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Flight Loads Data for a Boeing 737-400 in Commercial Operation

April 1996

Final Report

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16. Abstract

This report presents the flight data collected in 1993 from one Boeing 737-400 during routine commercial operation. The data collection program is part of a joint FAA/NASA effort to develop a flight recorder to obtain statistical loads data on commercial transport (FAR Part 25) aircraft during routine operations.

During this prototype data collection program, 593 flights of operational flight loads were collected. Of these, 535 flights representing 817.7 hours, provided usable data. NASA developed the specifications for the recording system, defined the recording format, reduced the data to time histories of engineering units, and tested and evaluated the algorithms for data reduction and statistical reporting. The University of Dayton Research Institute (UDRI) received the flight loads data and data review software from NASA. UDRI developed software to reduce the flight loads data and obtain additional parameters such as derived gust velocity and continuous turbulence gust intensity.

The data reduction includes, but is not limited to, analysis of e.g., accelerations, airspeeds, altitudes, flaps usage, and takeoffs and landings. Data are typically presented in cumulative distribution function or cumulative counts normalized to nautical mile or 1000 hours. Comparisons of typical usage with published FAR's are also presented.

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PREFACE

The Service Life Management Group of the Structural Integrity Division of the University of Dayton Research Institute performed this work under Federal Aviation Administration (FAA) Grant No. 93-G-051 entitled "Research Leading to the Development of Commuter Airlines Structural Integrity Management." The Program Monitor for the FAA is Mr. Thomas DeFiore of the FAA Technical Center at Atlantic City International Airport, New Jersey, and the Program Technical Advisor is Terence Barnes of the FAA Aircraft Certification Office in Seattle, Washington. Dr. Joseph P. Gallagher is the Principal Investigator for the University of Dayton. Co-Principal Investigators are Mr. F. Joseph Giessler, Dr. Alan P. Berens, and Mr. Larry G. Kelly. Mr. Donald A. Skinn performed the data reduction and statistical presentation. Ms. Peggy C. Miedlar performed data analysis and prepared this report. Mr. Larry Kelly provided oversight direction for this effort. Ms. Marylea Barlow compiled and formatted this report for publication. Mr. Robert W. Hoyng and Mr. Charles J. Middleton assisted with graphical presentations.

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[illegible]

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

$\overline{A}$	aircraft PSD gust response factor
a	speed of sound (ft/sec)
BBS	body balance station
$\bar{c}$	wing mean geometric chord (ft)
$\overline{C}$	aircraft discrete gust response factor
C_{L_α}	aircraft lift curve slope per radian
$C_{L_{max}}$	maximum lift coefficient
CAS	calibrated air speed
CDF	cumulative distribution function
c.g.	center of gravity
DFDAU	Digital Flight Data Acquisition Unit
DFDR	Digital Flight Data Recorder
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
fpm	feet per minute
F.S.	front spar
F(PSD)	power spectral density function
g	gravity constant, 32.17 ft/sec^2
Hp	pressure altitude, (ft)
K_g	discrete gust alleviation factor, $0.88\mu/(5.3 + \mu)$
KCAS	knots calibrated air speed
KEAS	knots equivalent air speed
KIAS	knots indicated air speed
kts	knots
L	turbulence scale length (ft)
MB	megabyte
Mhz	megahertz
n	load factor (g)
N	number of occurrences for U_σ (PSD gust procedure)
NASA	National Aeronautics and Space Administration
nm	nautical mile
n_x	longitudinal acceleration (g)

[illegible]

derived [illegible]
[illegible]

design [illegible]
design [illegible]
[illegible]
true air[illegible]

gross weight [illegible]

incremental [illegible]

incremental [illegible]
incremental [illegible]
incremental [illegible]

µ airplane mass [illegible]

μ_g statistical [illegible]

ρ air density [illegible]
ρ_0 standard [illegible]

σ standard [illegible]

φ bank angle (degrees)

EXECUTIVE SUMMARY

The University of Dayton is supporting Federal Aviation Administration (FAA) research on the structural integrity requirements for the US commercial transport airplane fleet. The ultimate objective of this research is to provide information which will enable the FAA to better understand and control those factors that influence the structural integrity of commercial transport aircraft. This activity supports the overall objectives of the FAA transport flight loads data collection program which are (a) to determine whether the loading spectra being used or developed for the design and test of both small and large aircraft are representative of operational usage and (b) to develop structural design criteria for future generations of small and large aircraft. Presented herein are analyses and statistical summaries of data collected from 535 flights representing 817.7 flight hours of typical B737 usage.

1. INTRODUCTION

The FAA and NASA [illegible] a flight recorder system to obtain statistical loads [illegible] (FAR), Part 25, Commercial Transport Aircraft During [illegible]. NASA [illegible] the specifications for the recording system, defined [illegible] the algorithms for data reduction and statistical [illegible] to the FAA. In 1993, a commercial airline [illegible] recorder in a [illegible] airplane and periodically provided FAA/NASA with [illegible] for [illegible] and analysis. NASA carefully reviewed 39 [illegible] for the statistical purposes of this program. NASA then [illegible] history files to the University of Dayton Research Institute (UDRI) for [illegible]. In [illegible], a total of 593 flights of operational flight loads [illegible] of the B737-400 aircraft. Of these data, 535 flights, [illegible] data. The time-history data collected under the joint FAA/NASA program were provided to UDRI on high-density magneto-optical disks in binary unit files. [illegible] developed by UDRI transformed these data into the statistical and graphical formats [illegible] in this report.

This report reviews both [illegible] and the data processing procedures and also summarizes the flight recorder data. Reference 1 contains the data development procedures. Section 2 describes the data [illegible], section 3 describes the processing of the time history flight loads data for [illegible] and section 4 presents the flight recorder data.

There is similarity in flight loads data requirements for commuter aircraft designed per carrier rules of FAR Part 23, and for large commercial aircraft designed per FAR, Part 25. Since flight loads data are more readily [illegible] for the Part 25 aircraft than for the Part 23 aircraft, the research in this report can [illegible] into the Part 23 aircraft operational conditions versus design conditions. Also, the [illegible] and implementation of the commuter aircraft data recording program being developed by UDRI can benefit significantly from knowledge gained from the on-going large transport flight loads monitoring program.

2. DATA COLLECTION PROGRAM.

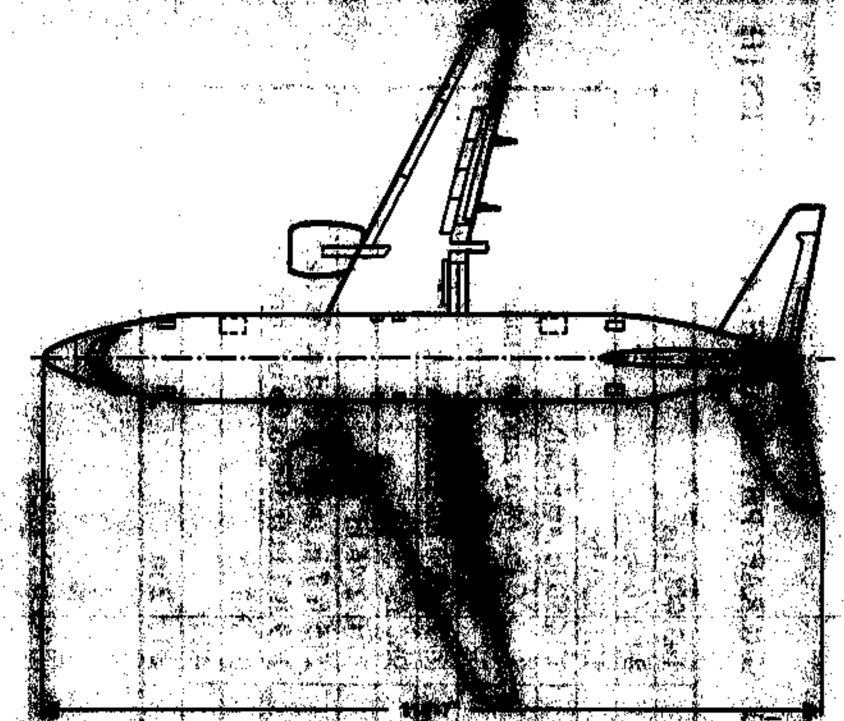
The flight data summarized in this report were obtained from a Boeing 737-400 commercial transport aircraft during [illegible]. The flight data were collected by an on-board recorder, transferred to a ground processing station, and reduced to time-history format. Table 1 lists the parameters that were recorded along with their sampling rates and table names. The significance of table name is discussed in section 2.2.

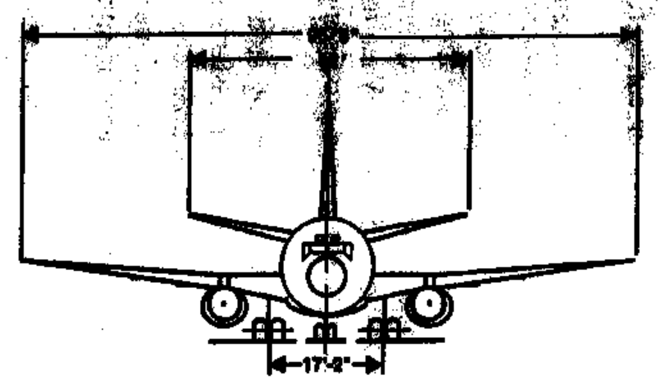
[redacted]

2.1 DESCRIPTION OF A…

…igure 1 shows front, top, and … identifies its major … dimensions. Table … aircraft.

Maximum Taxi Weight	143,000 lbs.
[illegible] Weight	77,[illegible]
[illegible] Fuel Weight	8[illegible] ... w/o [illegible] Tank
2 [illegible]-3 Engines	@ ~22,[illegible] static thrust, each
[illegible]	





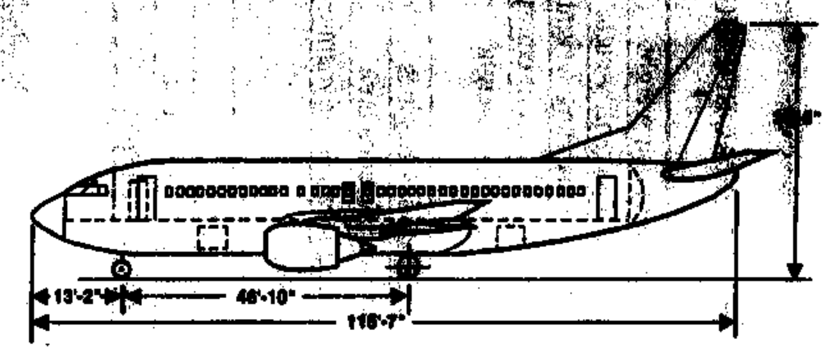


FIGURE 1. BOEING 737-400 AIRCRAFT DESCRIPTION

[illegible] TERISTICS [1]

[illegible] tail) [illegible]

[illegible] A COLLECT [illegible]

[illegible] processing s [illegible] borne data collection [illegible] and (2) a ground [illegible] processing system is [illegible] d below. A s [illegible] 2. A description of the [illegible] system design [illegible]

The airborne data collection [illegible] on Unit (DFDAU), a Digital Flight Data Recor [illegible] R). The DFDAU [illegible] sensor signals and [illegible] the POR. The POR [illegible] programmed to start rec [illegible] The POR is equipped [illegible] magneto-optical d [illegible] whereas the DFDR [illegible] hour looptape. [illegible] from the POR and [illegible] to the ground [illegible]

The ground data processing [illegible] computer and functions [illegible] the process of tr [illegible] format onto hard disk. Included in these functions [illegible] sensitive parameters, and [illegible] of the data into [illegible] sensitive are those which can be used to readily [illegible]

The collected data are automat [illegible] in table 3. If a value is outside the limits, the record [illegible] the validity of the data point. Each recorded [illegible] appropriate reasonable or maximum value at start up, [illegible] as needed. Flights having any out-of-tolerance parameters [illegible]

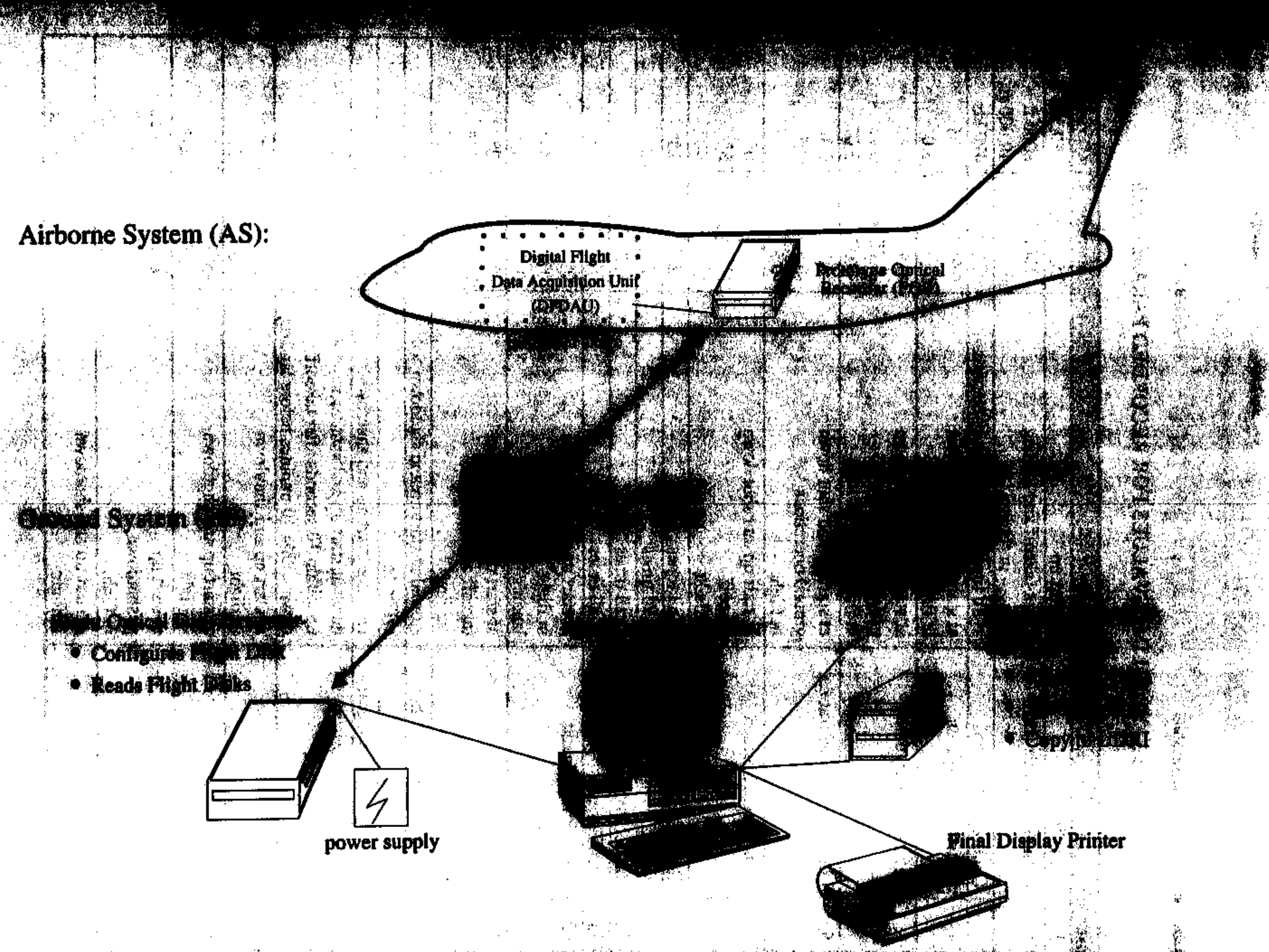

Airborne System (AS):
Digital Flight
Data Acquisition Unit
(DFDAU)
Reads Flight Disks
power supply
Final Display Printer

FIGURE 8.

TABLE [illegible] PARAMETERS

[illegible]	[illegible]	[illegible]	[illegible]	1[illegible]
[illegible]	[illegible]	[illegible]	[illegible] ft	8000 ft 40,000 ft
[illegible]	[illegible]	[illegible]	[illegible] kts	420 kts
[illegible]	[illegible]	[illegible]	[illegible]	1.05 2.0
[illegible]	[illegible] Acceleration	[illegible]	[illegible]	0.10 0.25 0.07
[illegible]	[illegible] Acceleration	[illegible]	[illegible]	0.1 0.5 0.5
[illegible]	[illegible] Position	[illegible]	[illegible]	0° 5° 40°
[illegible]	[illegible]	[illegible]	[illegible]	25°
[illegible]	[illegible]	[illegible]	[illegible]	25°
[illegible]	[illegible]	[illegible]	[illegible]	30°
[illegible]	[illegible]	[illegible]	[illegible]	17°
[illegible]	[illegible] Position	[illegible]	[illegible]	0° 40° 45°
[illegible]	Throttles 1 and 2	[illegible]	[illegible] 0 0	2° 55° 65°
[illegible]	Thrust Reverser Position	[illegible]	[illegible]	1
[illegible]	Autopilot Status	[illegible]	[illegible]	1
[illegible]	Gear Switch [illegible]	[illegible]	[illegible]	1
[illegible]	Landing Gear Position	[illegible]	0	1
[illegible]	Pitch Attitude	[illegible]	-5° -10°	3° 22°
[illegible]	Bank Attitude	[illegible]	-5° -45°	5° 45°
[illegible]	Mach Number	[illegible]	[illegible] -0.02 +0.16	+0.02 +0.02 +0.82
[illegible]	Ground Speed	[illegible]	0 0	4 kts 800 kts

[illegible] time history files [illegible] a Microsoft Access [illegible] of the parameters [illegible] table 1. [illegible] table 1, along with [illegible] rates for [illegible] the ground processing [illegible] and the [illegible] optical disk for the flight.

[illegible] DATA REDUCTION

[illegible] software, and time history [illegible] passenger aircraft from [illegible] statistical presentation [illegible] required parameters.

2.1 DATA PROCESSING [illegible]

[illegible] provided to UDRI on [illegible] on a 90 MHz Pentium computer. The [illegible] Each file contained the data for one flight. The [illegible] Flight File to allow the user to view time [illegible] surfaces.

The normal acceleration [illegible] because n_z is important in determining both the [illegible] flights contained extremely high and/or low n_z [illegible] end of the flight. Other parameters were [illegible] to deviate greatly from [illegible] values. [illegible] surges in the offended parameter. These [illegible].

[illegible] of the [illegible] following three reasons: (1) the aircraft never [illegible] terminated in midair (one flight), or (3) the FAA [illegible] a time history file (five flights).

This report required 16 [illegible] in table 1 to provide the [illegible] and [illegible]. These parameters exist as [illegible] tables in [illegible] database. ACCESS [illegible] to convert [illegible] as required by the UDRI summarization software.

[illegible]

[illegible] PHASES OF FLIGHT.

[illegible] flight was divided into [illegible] (taxi-out, takeoff roll, [illegible] roll, taxi-in), and [illegible] descent, approach). [illegible] defines the [illegible] not defined within [illegible] histories and [illegible] the conditions for [illegible] the starting [illegible] that the airborne [illegible] can occur several times [illegible] rate of climb and the [illegible] of the flaps. The [illegible] lists the phases of [illegible] and their correspon[illegible]

[illegible] STAGE LENGTH.

[illegible] is that portion of a [illegible] destination airport. The [illegible] length is determined [illegible] the point of liftoff [illegible] and the point [illegible] the calculation of [illegible] circle distance.

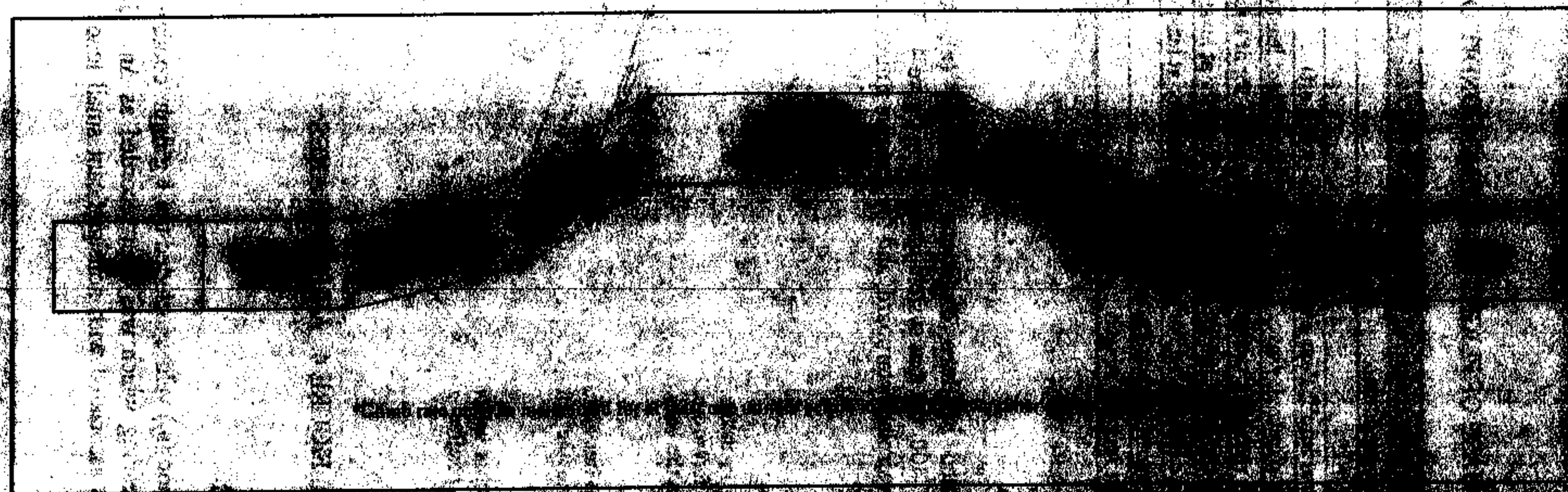


FIGURE 3. DESCRIPTION OF PHASES OF FLIGHT

[illegible]

[illegible]ELERATION [illegible]

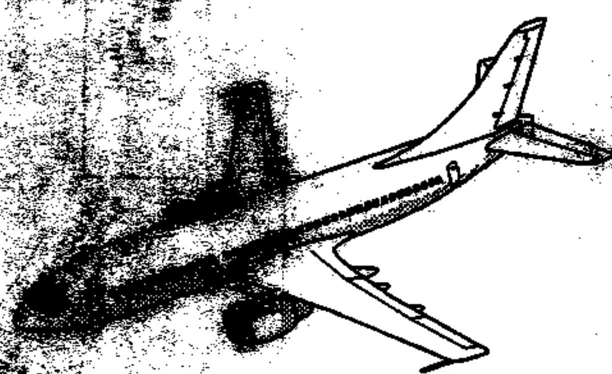
[illegible] data are [illegible] longitudinal (x), and [illegible]. For the Boeing [illegible] positive x direction [illegible] positive y direction [illegible] is up.

[illegible] Axes Definition

x = Body Balance Station ([illegible] The zero BBS is 540 [illegible] the wing front spar [illegible] The positive x direction [illegible]

y = The airplane centerline is [illegible] The positive y direction is [illegible] facing aft.

z = Water line zero is 208.1 in[illegible] the passenger floor. The [illegible] direction is up.



[illegible]1. Normal Acceleration (n_z)

The recorded normal accelera[illegible]n. The 1 g condition was removed from each n_z [illegible] In order to avoid the inclusion of peaks and valleys [illegible] variations, a threshold [illegible] Δa_n = [illegible] extract the [illegible]

[illegible] obtained from [illegible] counts per 1000 [illegible] Section 3.4.4.

[illegible] the aircraft [illegible] gust [illegible] theory. Most [illegible]

[illegible] angle [illegible]

Δa_n [illegible] (3)

[illegible] is the [illegible] assumed to be gust [illegible]

Δa_n [illegible]

[illegible] approach does [illegible] control inputs. [illegible] [3] suggest [illegible] induced by pilot [illegible] turbulence [illegible] response to the turbulence [illegible] accelerations which [illegible] points of rotation and [illegible] during takeoff and [illegible] removed during this [illegible] data reduction effort [illegible] but on commercial [illegible] maneuvers, [illegible] not substantially alter the statistics presented [illegible]

[illegible] calculated, [illegible] as three unique [illegible] The Δa_n [illegible] of a given acceleration [illegible] per [illegible] provided for each phase of flight and all phases [illegible] incremental normal load factor (airplane limit load [illegible] zone, only accelerations greater than ±0.05 [illegible] presentation.

[illegible] the data [illegible] the landing roll [illegible] of ±0.0025 g. [illegible]

[illegible] deadband is [illegible]

[illegible] Between-Mean [illegible] in the [illegible] and the method [illegible] acceleration [illegible] between-mean [illegible] This method [illegible] displacement [illegible] Only one [illegible] crossings of the [illegible] threshold zone [illegible] oscillations around [illegible] For the normal [illegible] is ±0.05 g; for [illegible] acceleration n_y the [illegible] accelerations n_x the threshold zone is ±0.0025 g.

FIGURE 5. THE "PE[illegible] CRITERIA

... is generated ... the deadband ... value ... is that ... into or ... the various ... peak ... also ... of current and previous ... acceleration values ... the deadband ... to the ...

...N

Above **Previous value is potential positive peak**	[illegible]	[illegible]	**Current acceleration ... same side of deadband ... previous.** ***If current > previous value, retain current value as potential positive peak and release previous.***
Within **At start of processing, or a peak was established but current acceleration value has not since gone outside of deadband**	[illegible]	[illegible]	**Current acceleration passes upward out of deadband.** ***Current value retained as potential positive peak.***
Below **Previous value is potential negative peak**	[illegible]	[illegible]	**Current acceleration passes through deadband** ***Previous value is classified as a negative peak.*** ***Current value retained as potential positive peak.***

ACCELERATION DEADBAND

normal acceleration

$$U_{de} = \frac{\Delta n_z}{\overline{C}} \quad (3)$$

Δn_z is ...

$\overline{C}$ is the ... degree of freedom ...

$$\overline{C} = \frac{\rho_0 V_e C_{L_\alpha} S}{2W} K_g \quad (4)$$

ρ_0 = 0.00...

V_e = equiv...

C_{L_α} = airc...

S = wing ...

W = gross ...

$K_g = \frac{0.88\mu}{5.3+\mu}$

$\mu = \frac{2W}{\rho g \overline{c} C_{L_\alpha} S}$

ρ = air density ... standard atmosphere table

g = 32.17 ft/s...

$\overline{c}$ = wing mean ...

[illegible] ive slope for the [illegible]

For [illegible] es a function of [illegible] of flap deflection [illegible]

[illegible]

[illegible] in terms of the [illegible] root-mean-square [illegible] U_{σ}, is [illegible] ation using the power [illegible] density [illegible]

$$U_{\sigma} = \text{[illegible]} \qquad (5)$$

where Δn_z = [illegible]

$$\bar{Z} = \text{[illegible]}, \frac{1}{ft/sec} \qquad (6)$$

ρ_0 = [illegible]

V_e = [illegible]

C_{L_α} = [illegible]

S = [illegible]

W = [illegible]

F [illegible]

$$\text{[illegible]} \qquad (7)$$

$\bar{c}$ = [illegible]

L = [illegible]

$$\mu = \text{[illegible]} \qquad (8)$$

ρ = [illegible]

g = 32.1 [illegible]

[illegible] the [illegible]

$$N = \frac{N_0(\text{[illegible]})}{N_0(\text{[illegible]})} \text{[illegible]} \qquad (9)$$

where $\bar{c}$, ρ, ρ_0, and μ are [illegible] ed as N counts at that U_{σ} value. This number of [illegible] per nautical mile (nm),

(10)

$$q = \frac{1}{2} \rho V^2 \quad (11)$$

ρ = [illegible]
V = [illegible]

... air speed ... [illegible] ... values and are ...

FLAP DETENTS

... flaps are extended, ... [illegible] ... setting as indicated in ... 7.

1	[illegible]
5	[illegible]
10	[illegible]
15	[illegible]
25	[illegible]
30	[illegible]
40	[illegible]

3.2 CALCULATED VALUES

To calculate derived gust velocity [illegible] ... and dynamic pressure, air density, equivalent air speed, [illegible] ... The determination of these ... explained here.

$\beta = \ldots$

$V_c = \ldots$

... speed is ... (a). The units of ... speed of ...

$V_T = \ldots$ (14)

... number is ... sound (a) is a function ...

$a = \ldots$ (15)

... Lift Curve Slope

... conditions with ... Mach number and altitude. ... flaps ... flap position and velocity ... The ... [1].

... NUMERICAL ...

In this section, the ... parameters presented in this section and which ... describe the presentation of the data, including ... possible, the FAR design requirements are plotted ...

[illegible]

[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	Figure 8
[illegible]	[illegible]	Figure 9 [illegible]
[illegible]	[illegible]	Figure 11
[illegible]	[illegible]	Figure 12 Figure 13 Figure 14
[illegible]	[illegible]	Figure 15
[illegible]	[illegible]	Figure 16
[illegible]	[illegible]	Figure 17
[illegible]	[illegible]	Figure 18 Figure 19 Figures 20 - 26
[illegible]	[illegible]	Figure 27
[illegible]	[illegible]	Figure 28 Figure 29
[illegible] Acceleration	[illegible]	Figures 30 - [illegible] Figures [illegible] - [illegible] Figures 40 - 45
[illegible] Acceleration	[illegible]	Figure 46
[illegible] Gust Loads	[illegible]	Figures 47 - 51
[illegible] GustLoads	[illegible]	Figure 52 Figure 53
[illegible] Gust	[illegible]	Figure 54 Figure 55
[illegible]	[illegible]	Figures 56 - 59
[illegible]	[illegible]	Figure 60
[illegible] equivalent	[illegible]	Figure 61
[illegible] Load	Range [illegible]	Figure 62

3.1 PRESENTATION OF [illegible]

[illegible] cumulative distribution [illegible] reverser was engaged [illegible] cumulative distribution [illegible] shown in figures 7 and 8 [illegible] respectively. In figure 7, the [illegible] time are shown on the

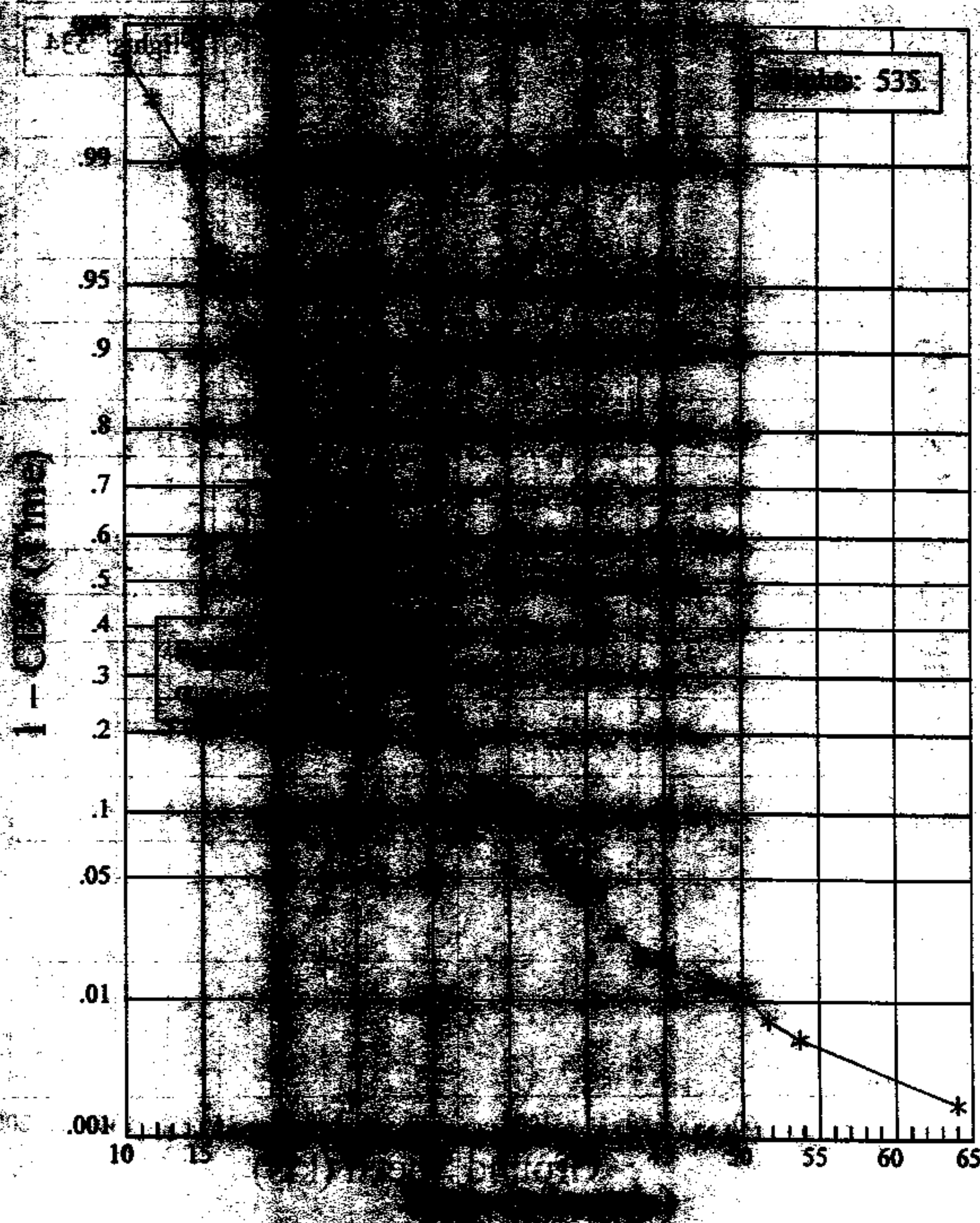


FIGURE 1 [illegible] OF SECONDS

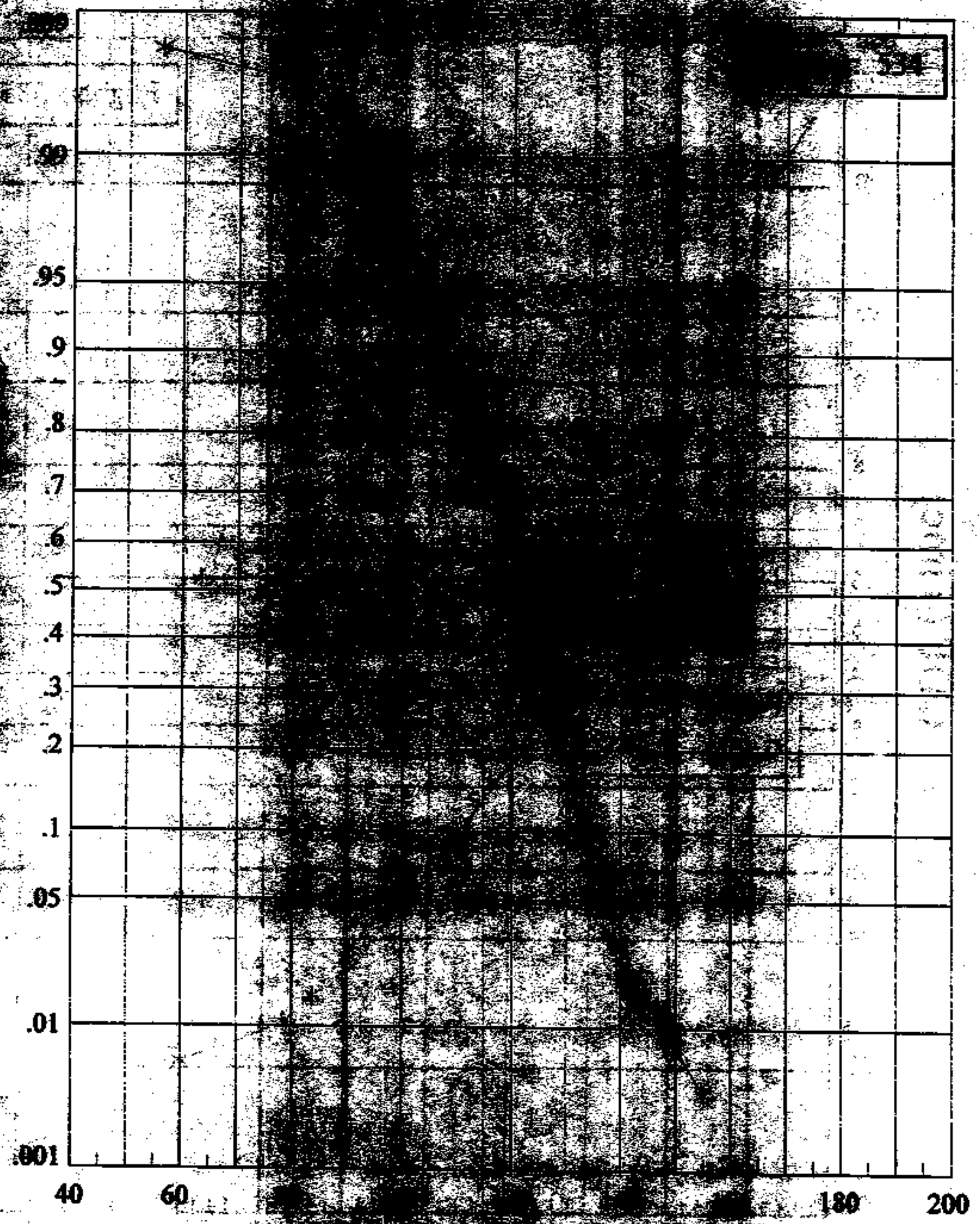


FIGURE 8. C[illegible]ED
AT[illegible]

[illegible] One of the [illegible] of these [illegible]

[illegible] These [illegible] landing, n_z [illegible]

[illegible] prior to liftoff [illegible] after touchdown, [illegible] touchdown.

[illegible] landing is shown [illegible] (takeoff rotation) [illegible] set of data [illegible] during landing [illegible] pitch [illegible] the maximum n_z peak [illegible] are also shown.

[illegible] cumulative [illegible] landing is shown by separate [illegible] in figure 15. [illegible] speed for each curve [illegible] ated. [illegible] ing.

Figure 16 shows [illegible] touchdown. The data are [illegible] as the [illegible] intersecting gross weight [illegible]

[illegible]

[illegible] cumulative [illegible] autopilot was engaged is shown [illegible] figure 17. The [illegible] on the plot.

[illegible]

Flap usage during [illegible] summarized in the histograms [illegible] in figures 18 [illegible] of time spent in each [illegible] both as a [illegible] and approach phases [illegible] also as a [illegible] present the cumulative [illegible] of [illegible] for each flap detent. The mean and standard [illegible]

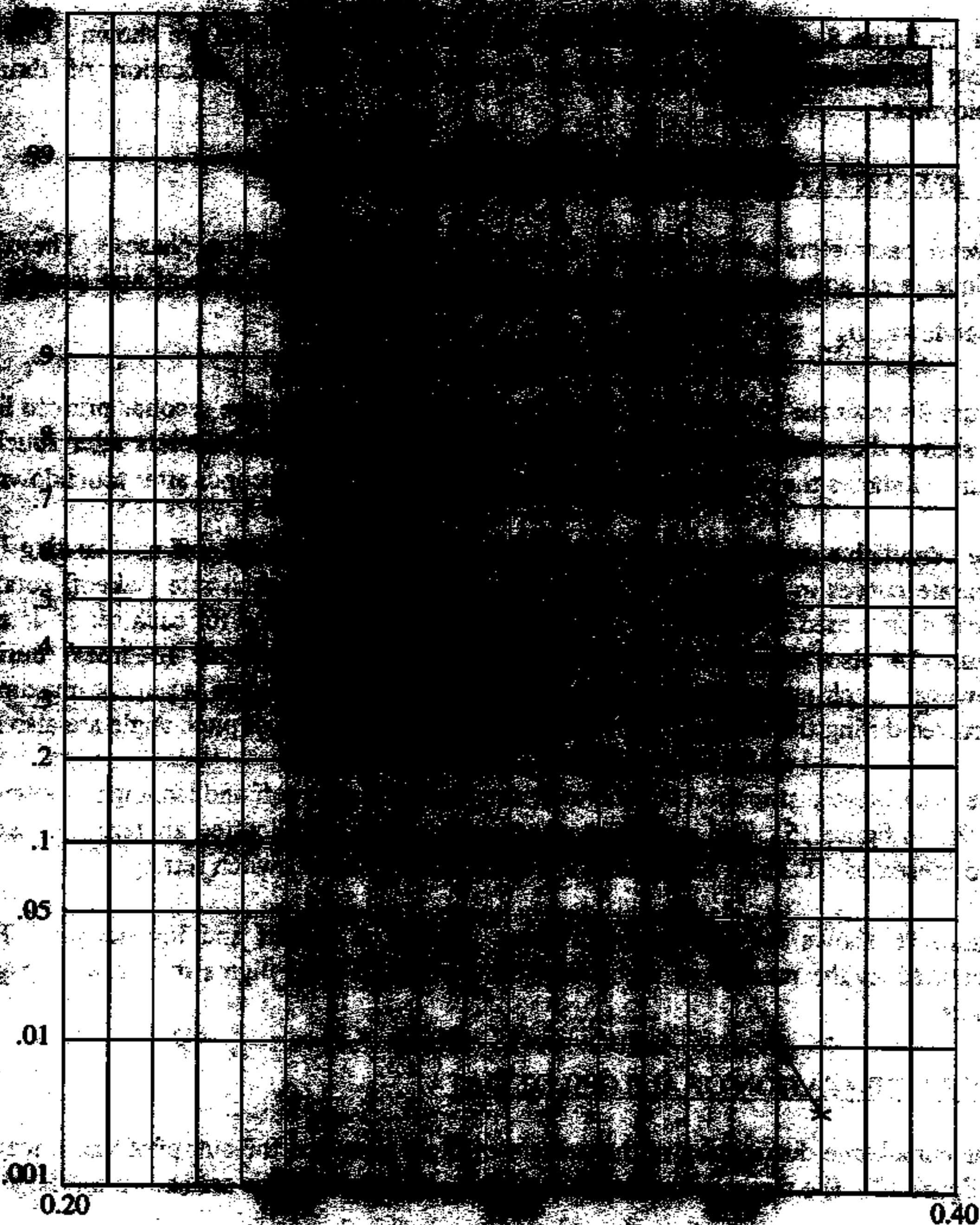


FIGURE 9. CUMULATIV[illegible] BEFORE TAKEOFF

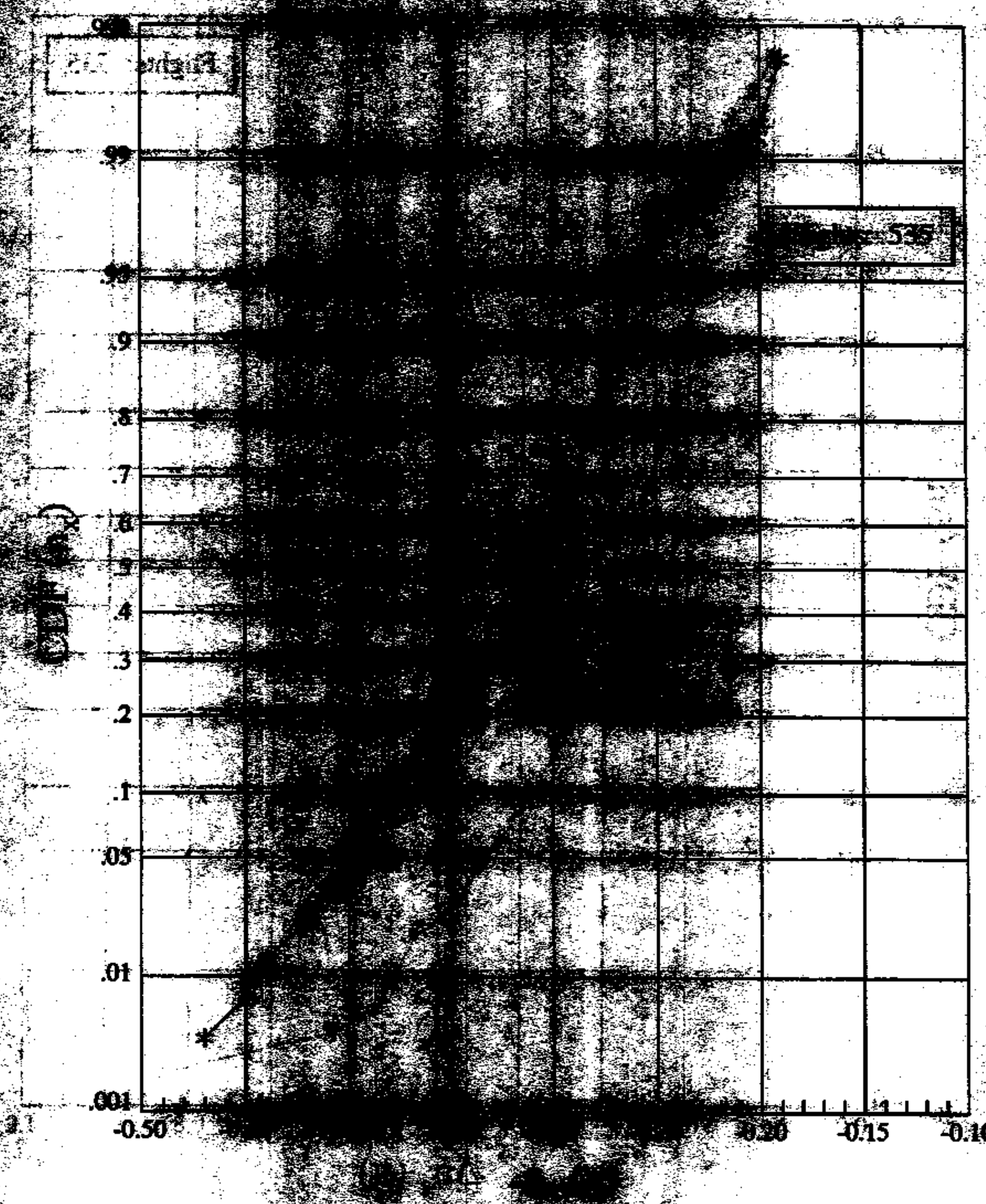


FIGURE 10. CU... n_x AFTER LANDING

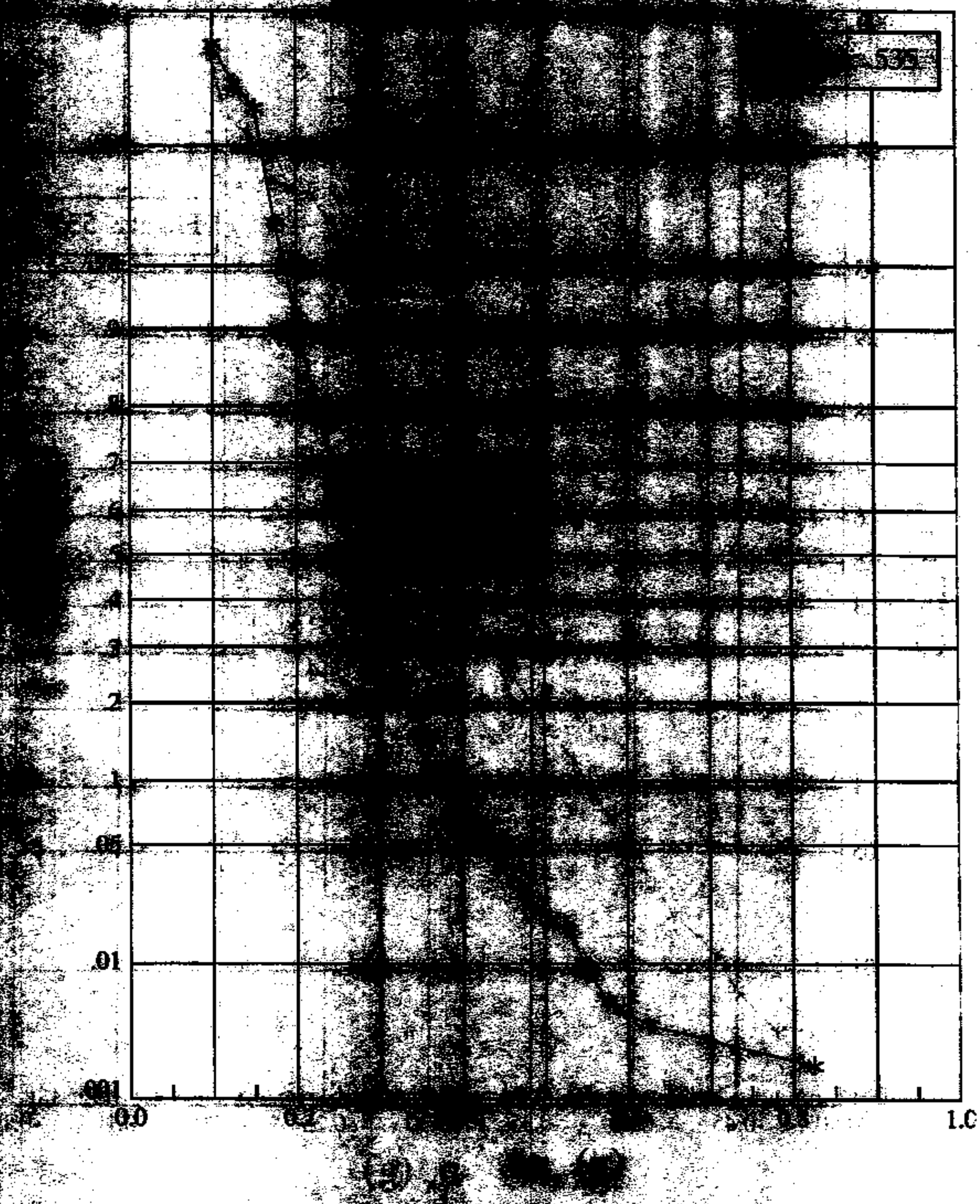


FIGURE 11. CUMULAT[illegible]TOUCHDOWN

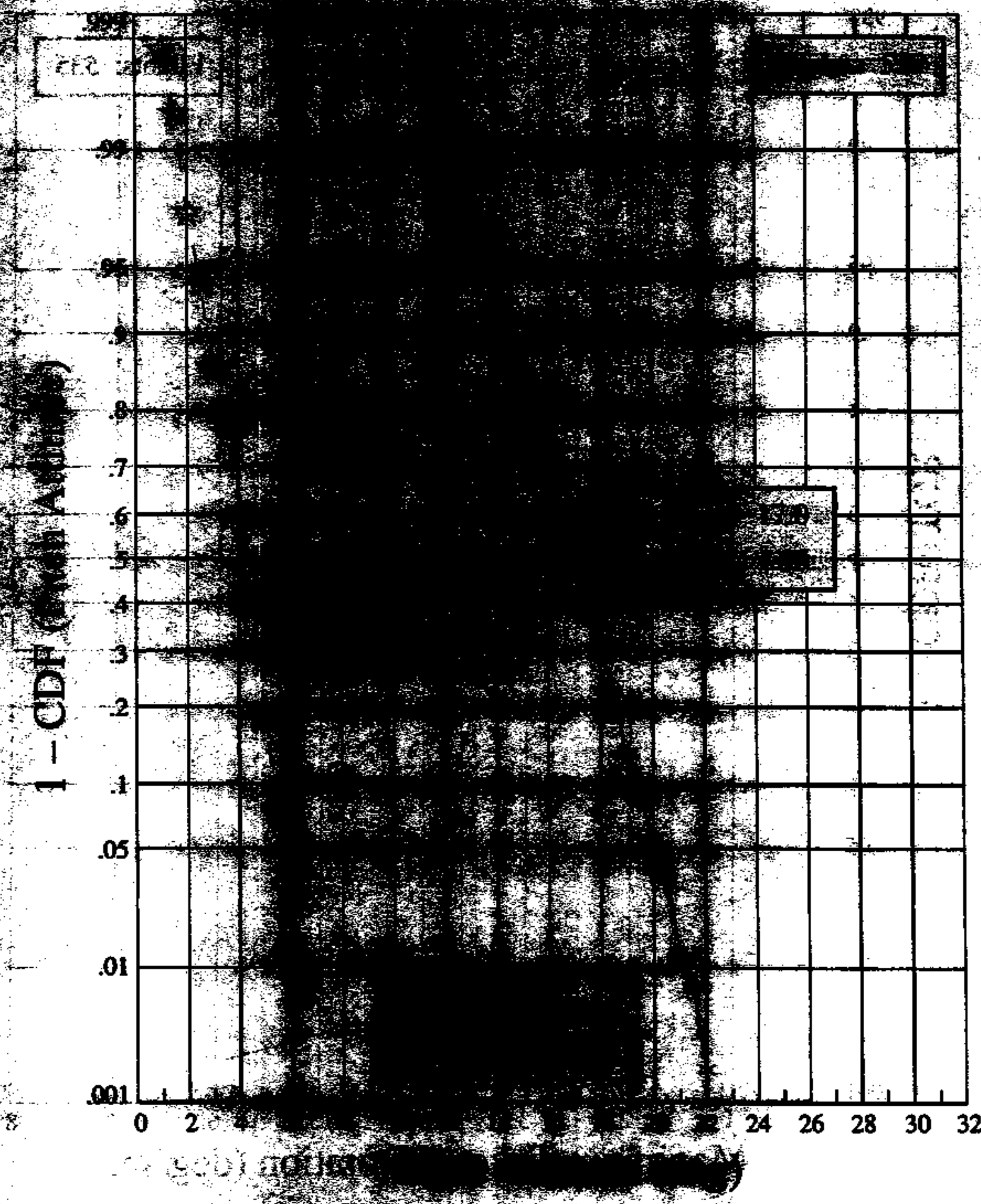


FIGURE 12. [illegible] PITCH ATTITUDE [illegible]

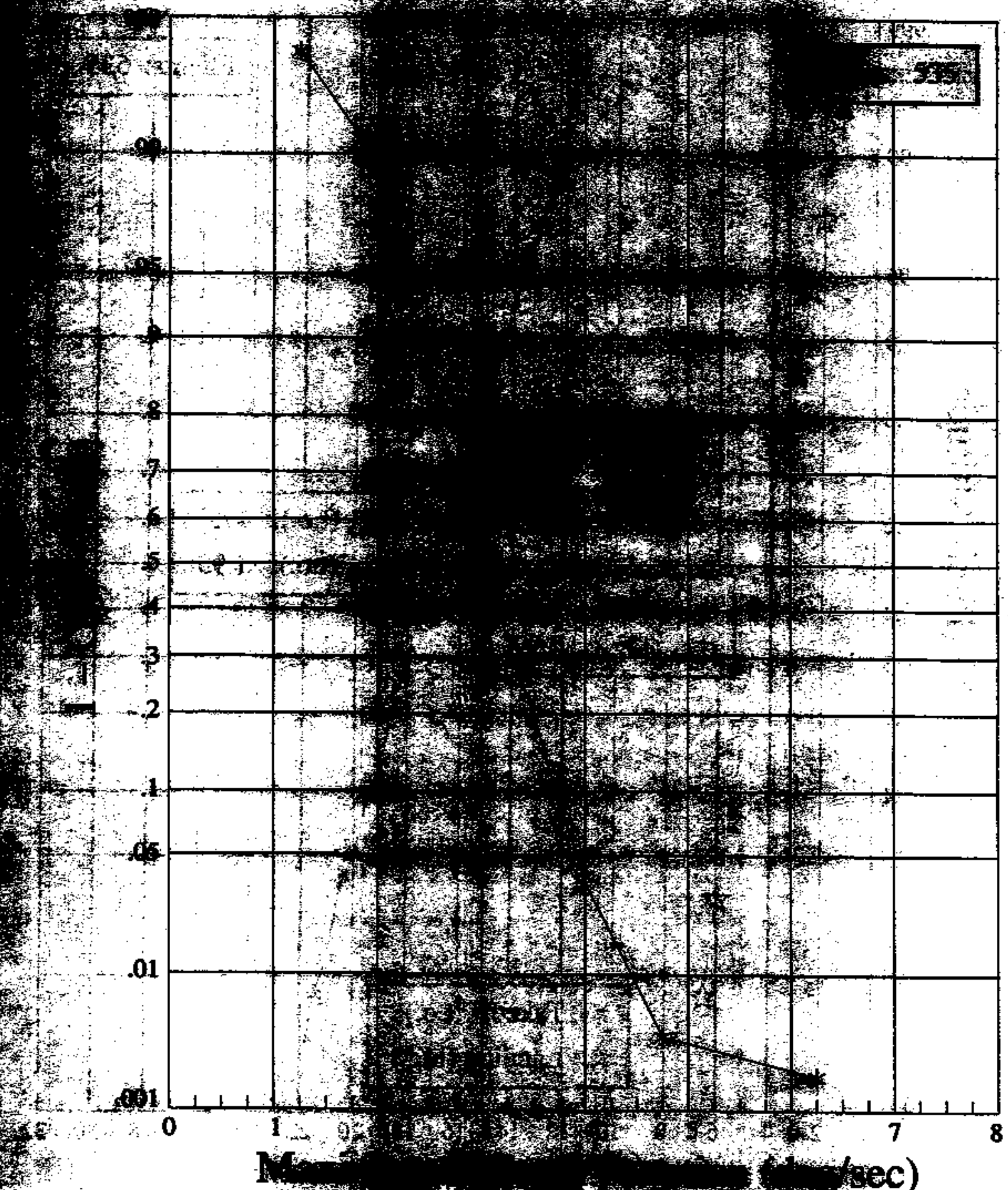


FIGURE 13. CUMULA[illegible] ROTATION

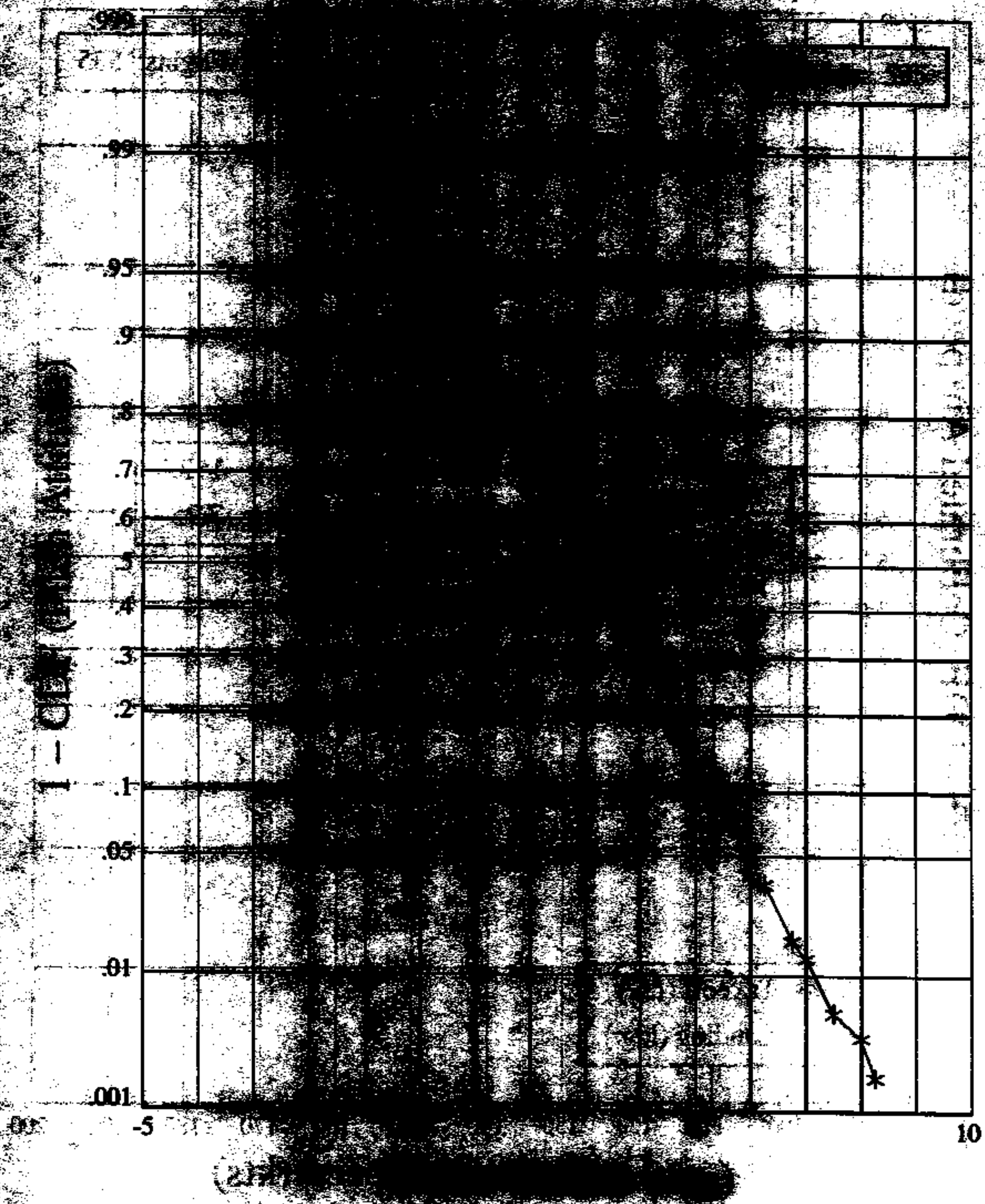


FIGURE 14. [illegible] PITCH ATTITUDE AT [illegible]

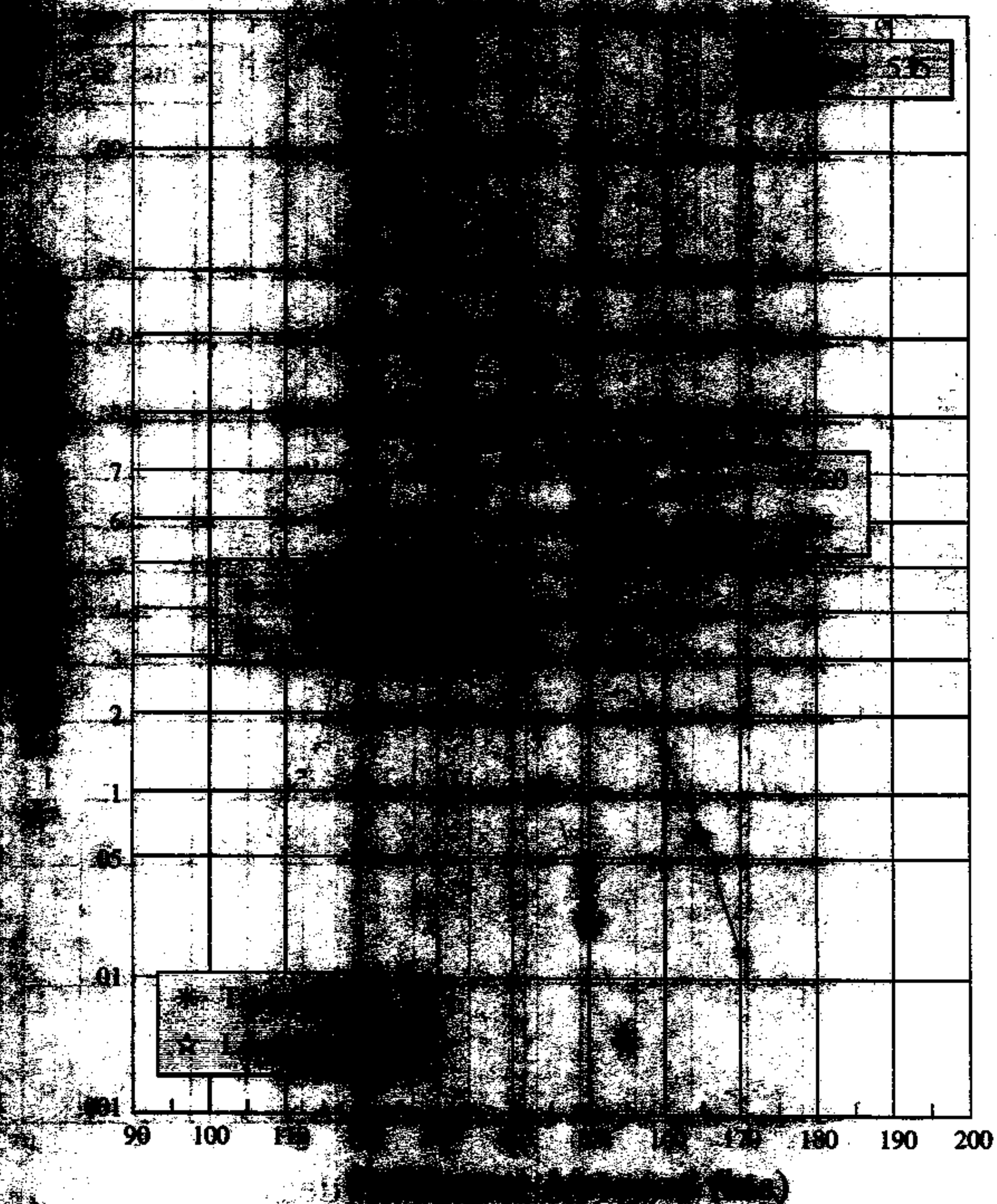
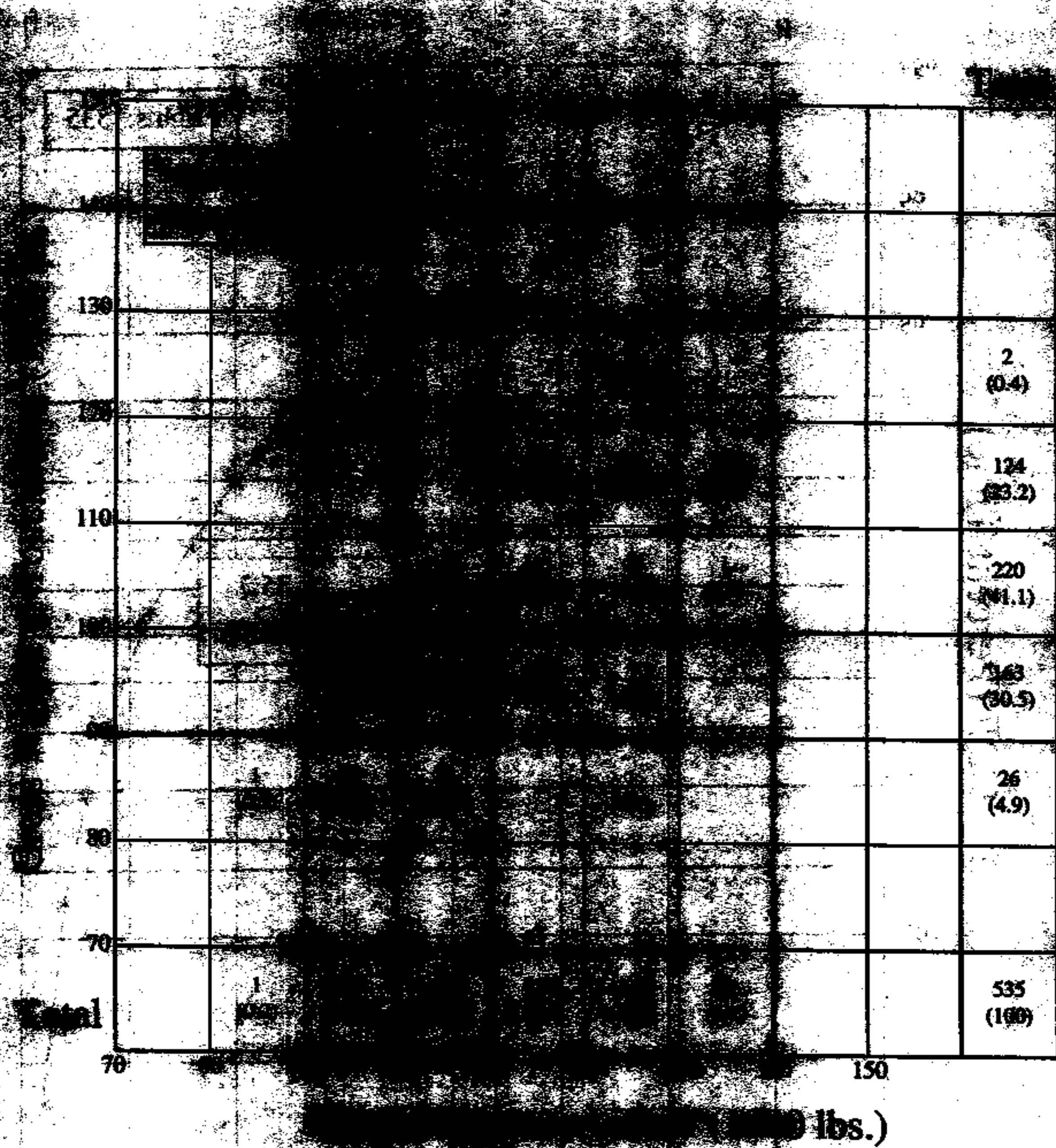


FIGURE 15. C[illegible] AIR SPEED DURING [illegible]



FIG[illegible] LIFTOFF
[illegible]TS)

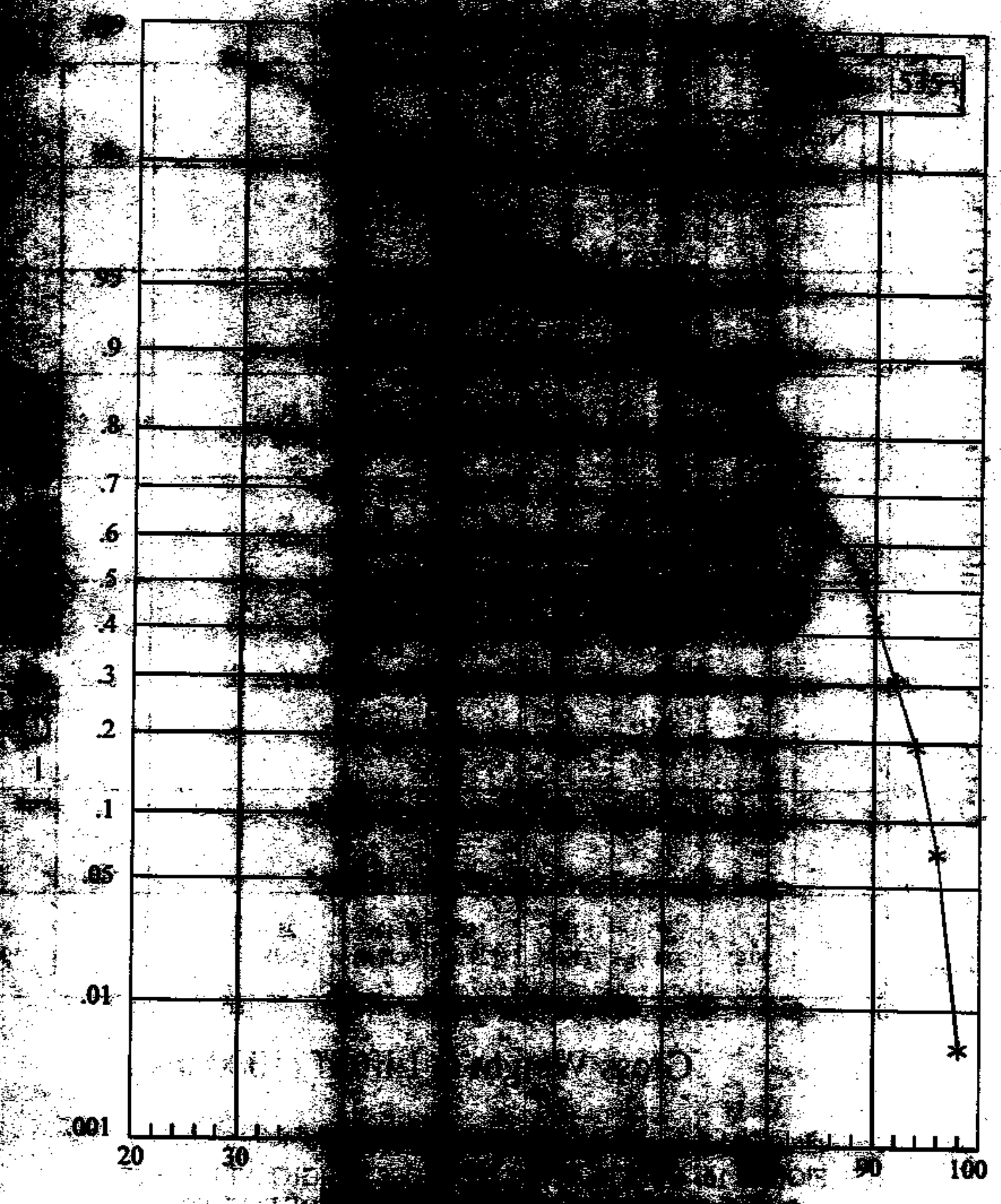
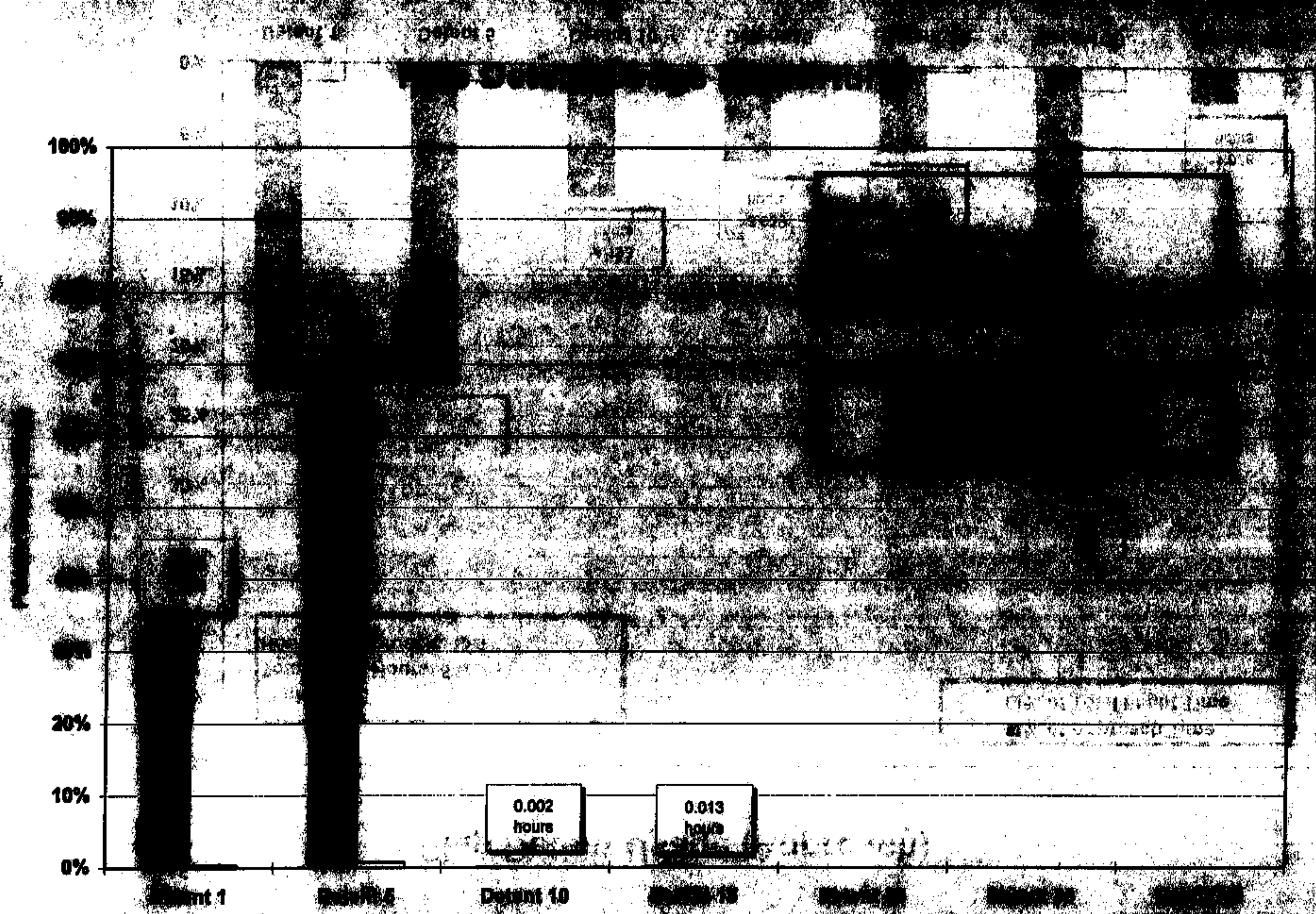


FIGURE 17. [illegible]



100%
20%
10%
0%
0.002
hours
0.013
hours
Detent 10

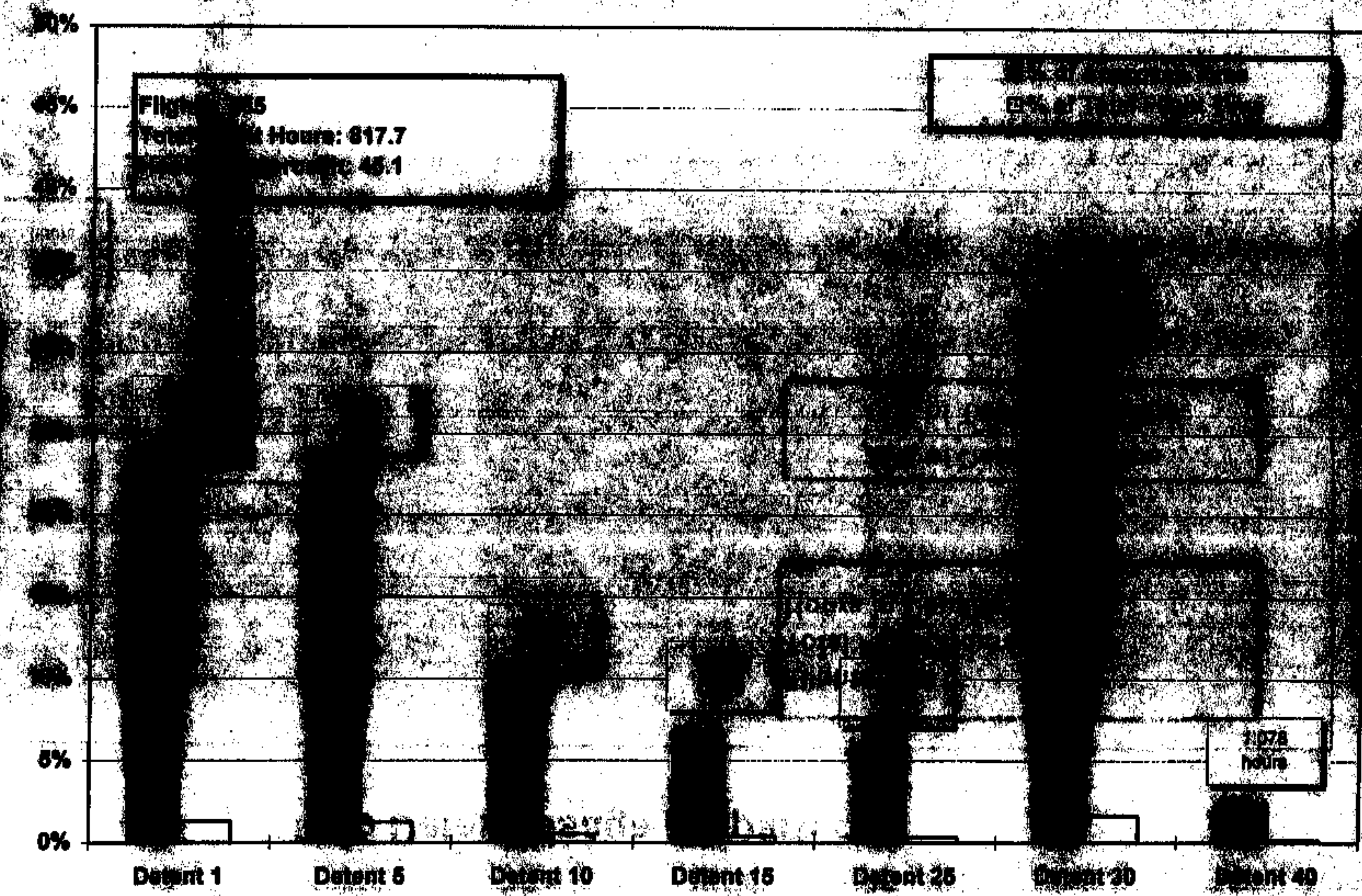


FIGURE 19. FLAPS USAGE BY FLAPS DETENT DURING APPROACH

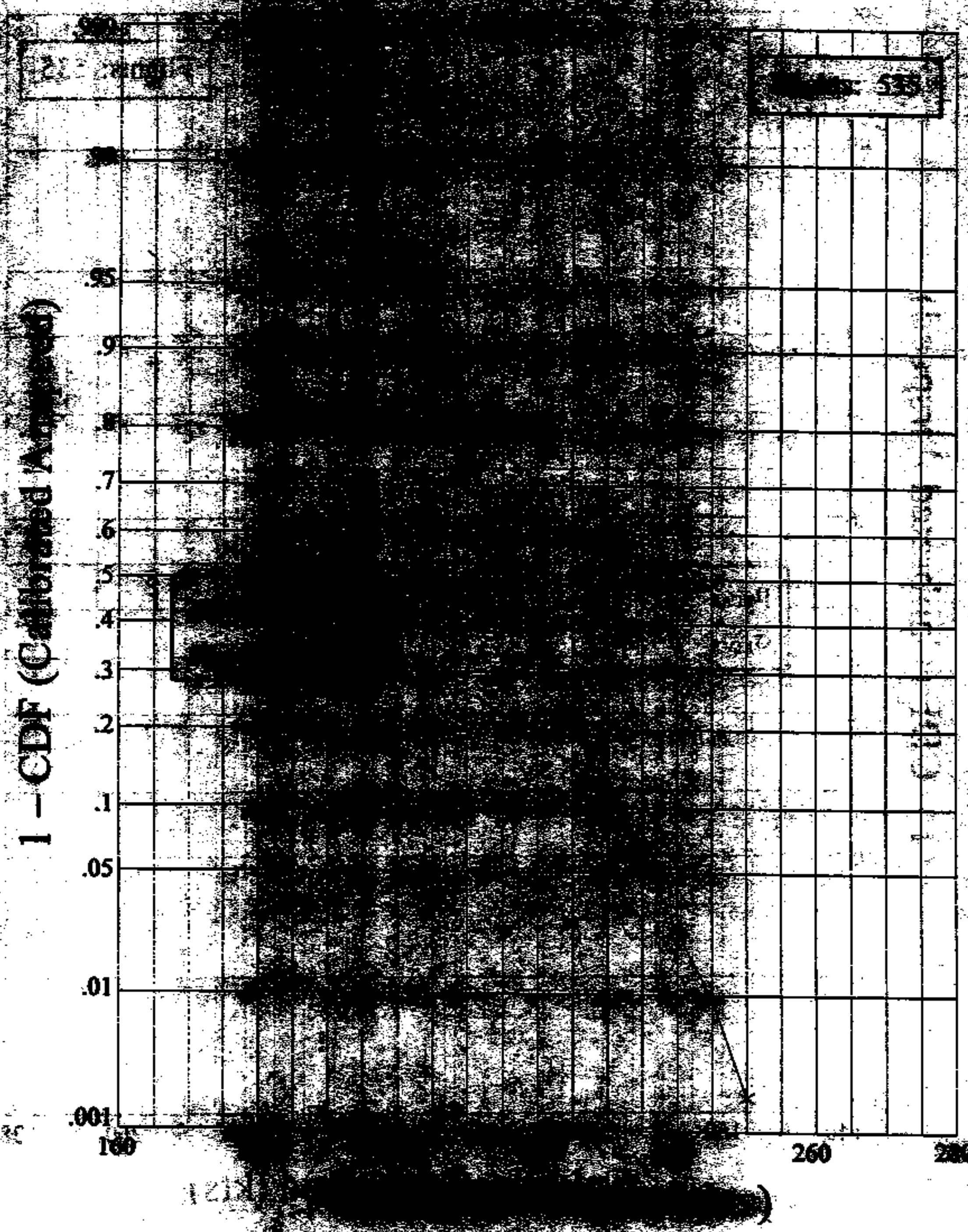


FIGURE 20. [illegible] AIRSPEED

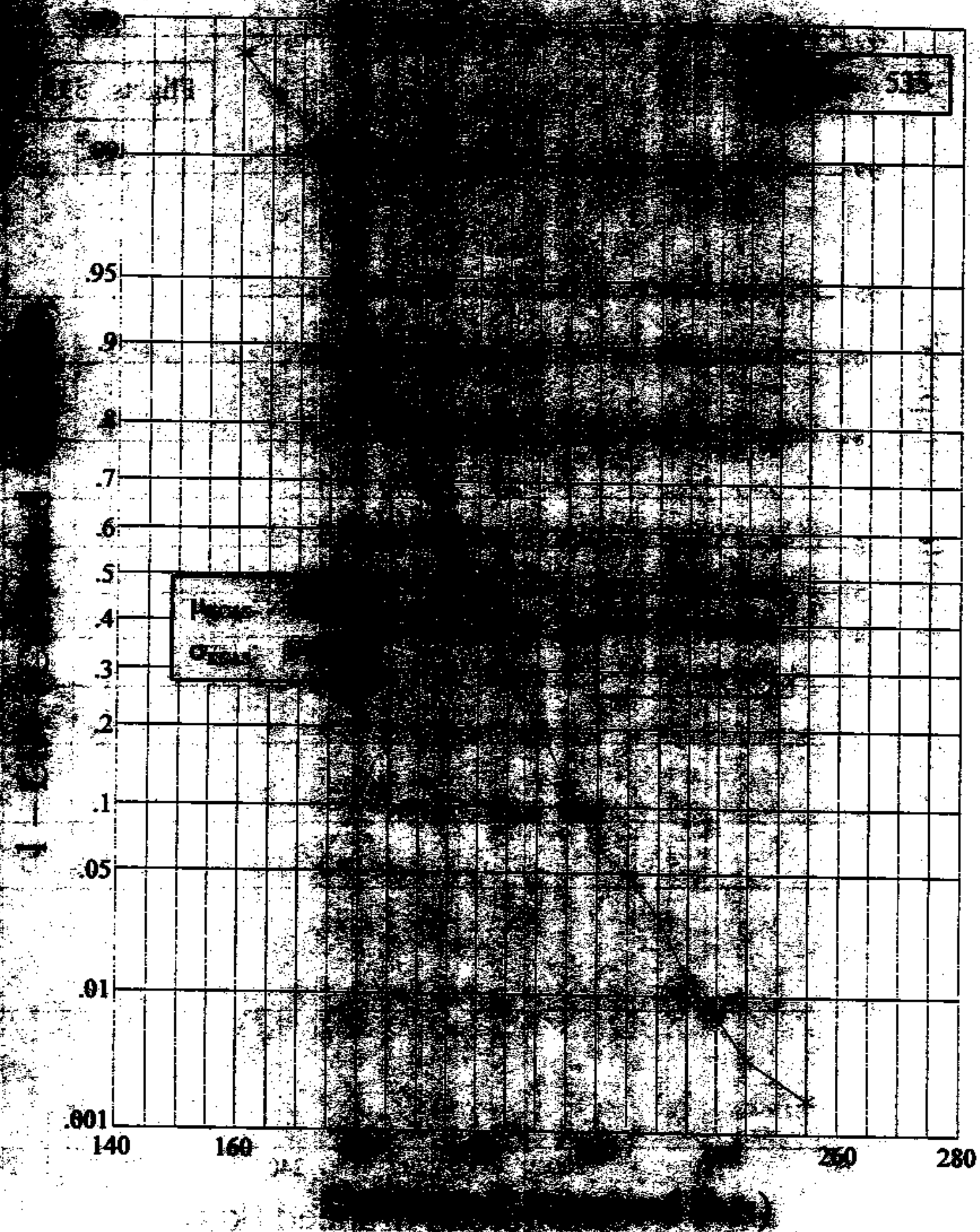


FIGURE 21. CLIMB [illegible] AIRSPEED AT PLA[illegible]

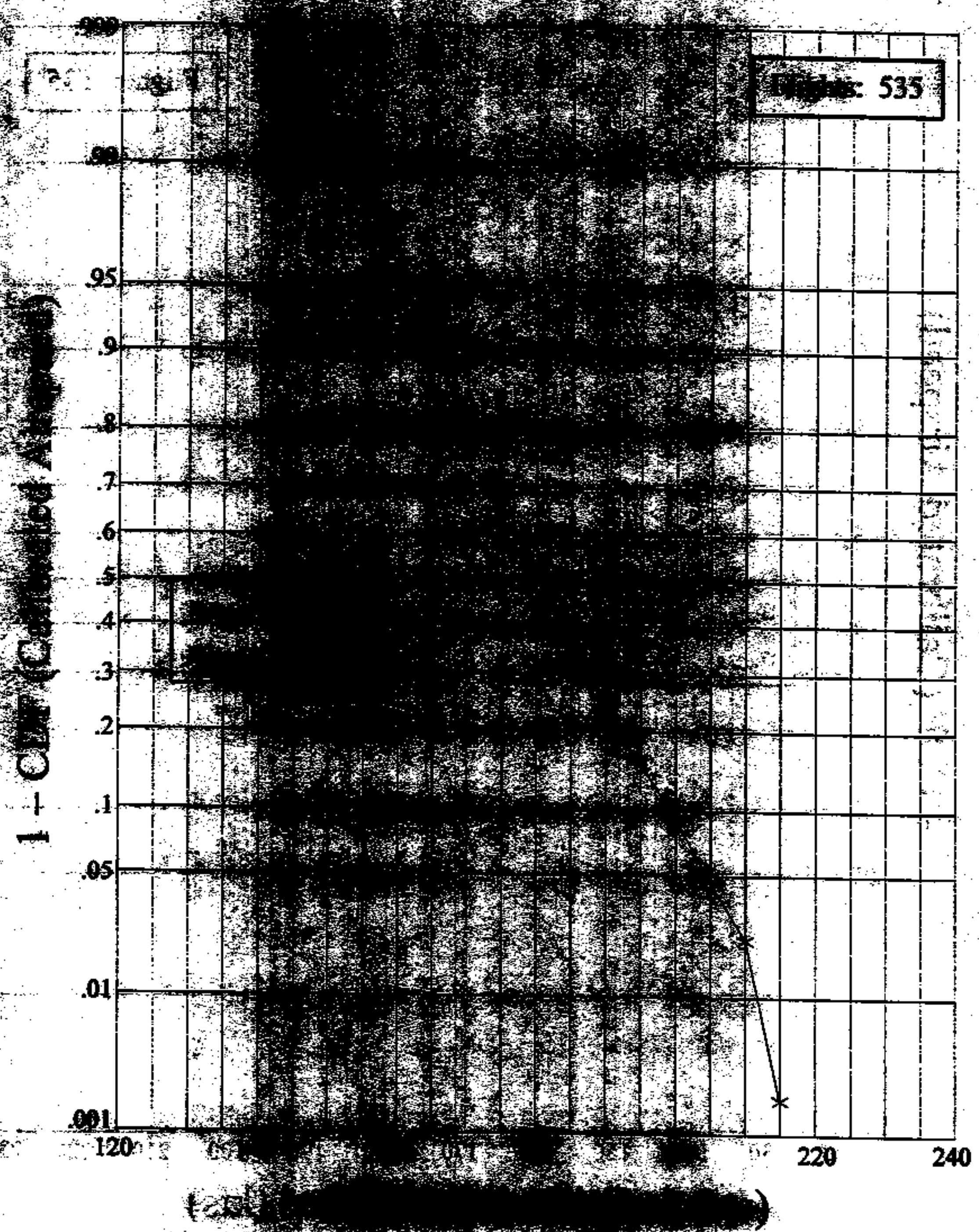


FIGURE 22 [illegible] AIRSPEED

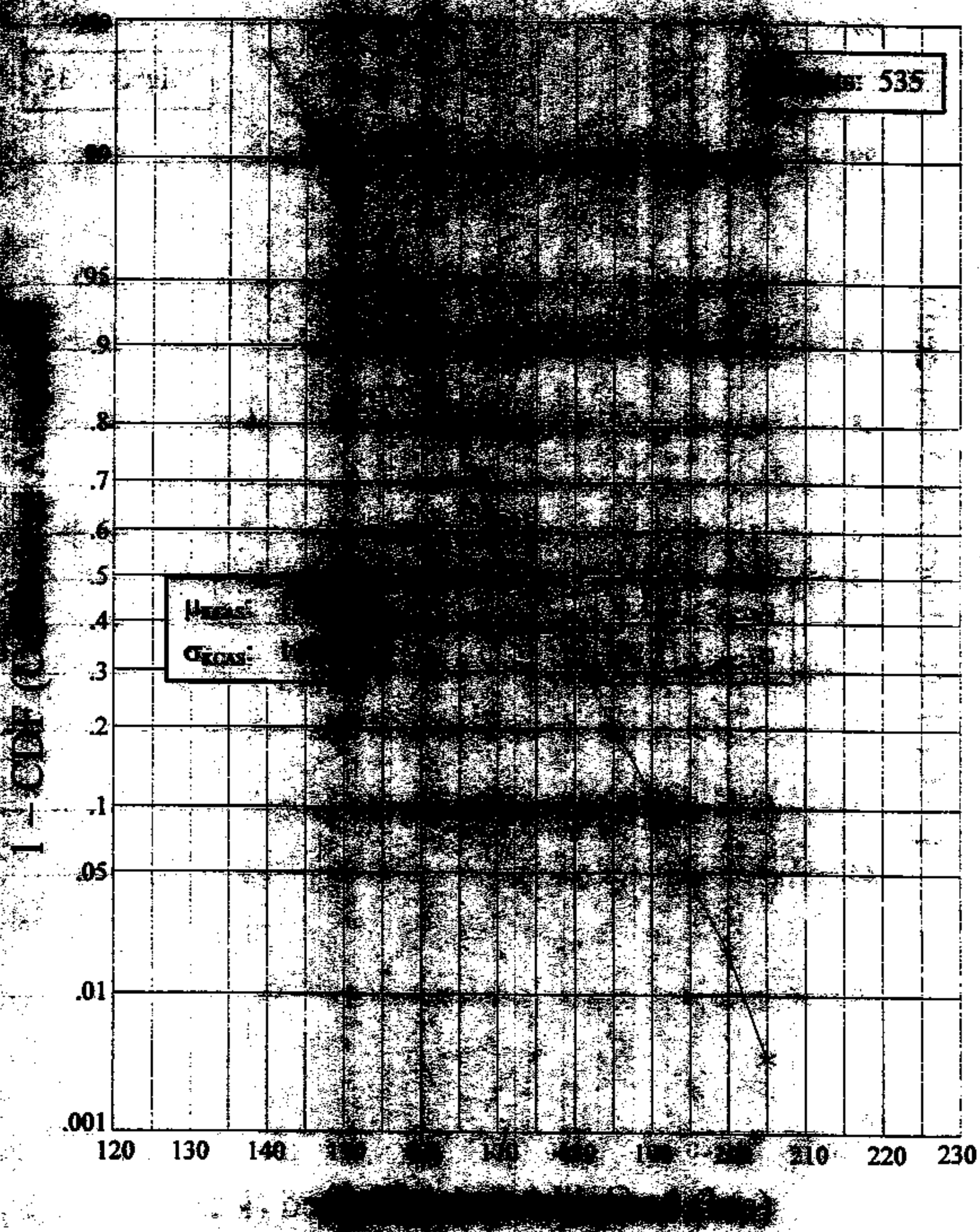


FIGURE 23. CUM[illegible] AIRSPEED
AT FLA[illegible]

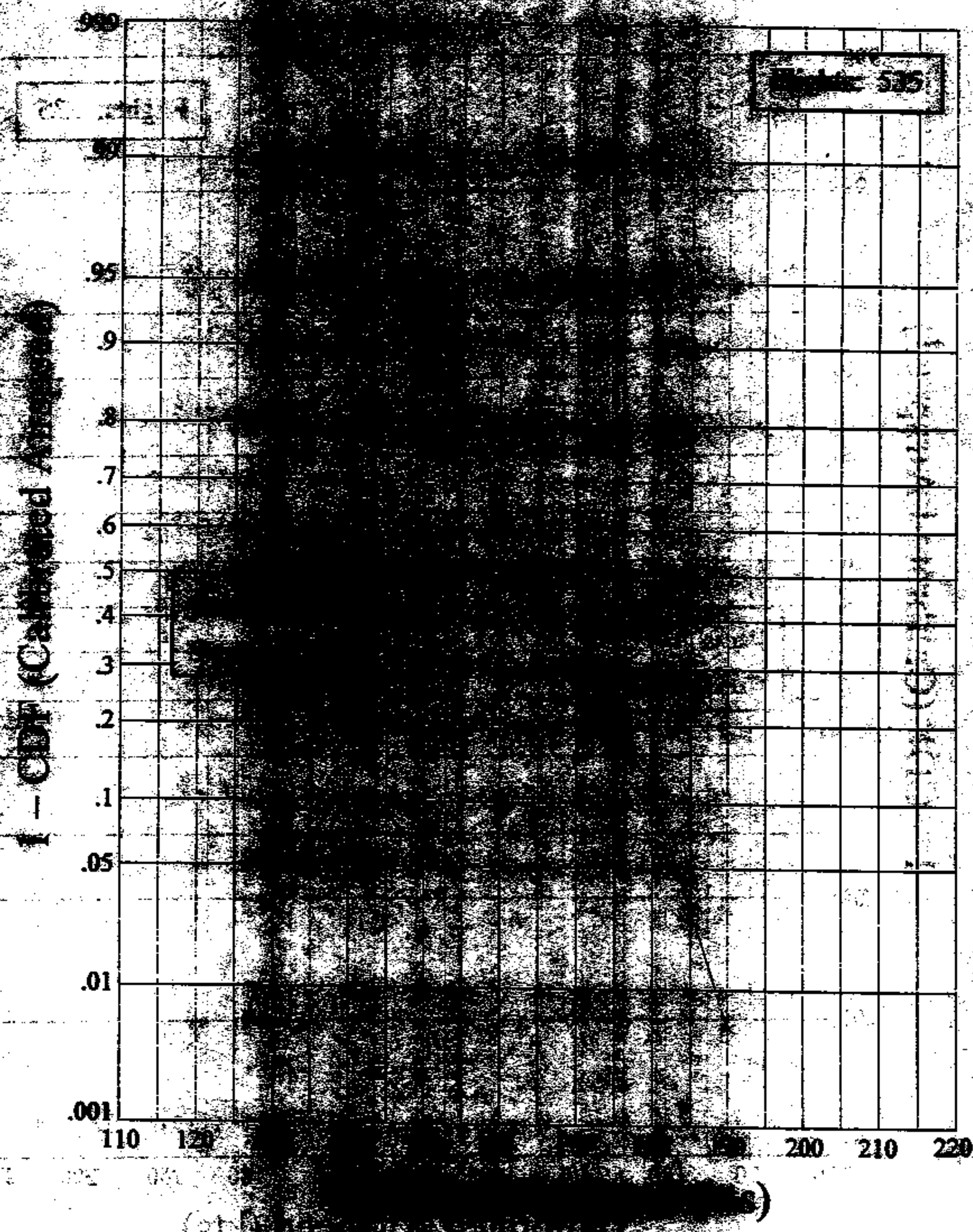


FIGURE 24. [illegible] TED AIRSPEED

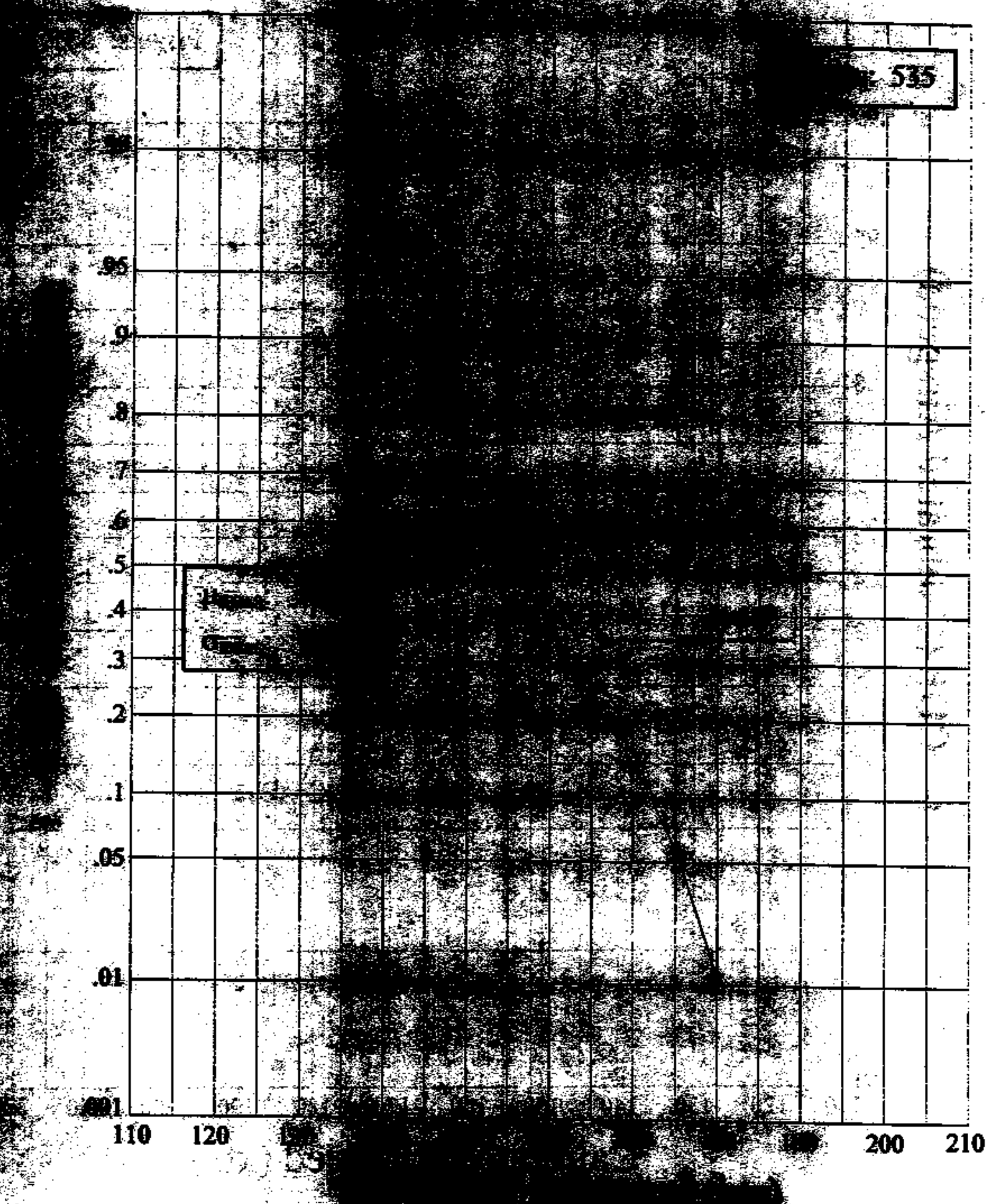


FIGURE 25. CU[illegible]SPEED
AT FLA[illegible]

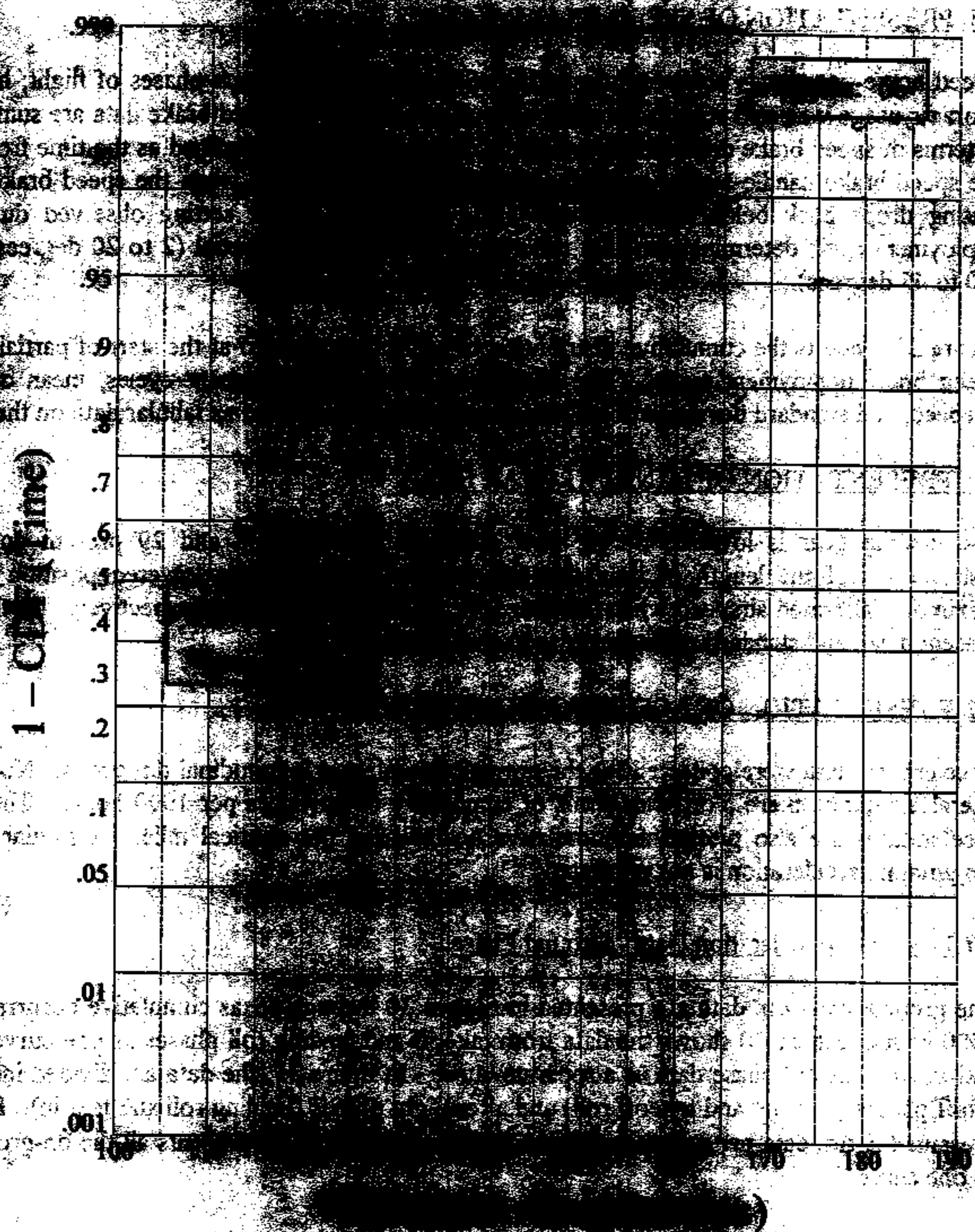


FIGURE 26. [illegible] TED AIRSPEED

[illegible] data, however [illegible] are summarized [illegible] during the [illegible] dispersion of the [illegible].

[illegible] of partial and full [illegible] mean [illegible] data on the plot.

[illegible]

[illegible] present cumulative [illegible] position and the [illegible]ly. Both figures [illegible]

[illegible]

[illegible]ation data were [illegible]ations. Normal and [illegible] acceleration are pl[illegible]eters. The normal [illegible]tions are also pl[illegible]. A similar plot for [illegible] acceleration is [illegible]

[illegible] Normal Accel[illegible]

[illegible] loads Δn_z dat[illegible] occurrences per [illegible]. Figure 30 [illegible] one curve and the [illegible] and taxi-out phase [illegible] divided into before [illegible]ses (taxi-out and [illegible] taxi-in). Figure 32 [illegible] the Δn_z data per [illegible] the on-ground data [illegible] curve.

[illegible] Normal Acceleration [illegible]

[illegible] the 1950s, it has [illegible] as a cumulative [illegible] of exceedance [illegible]737 are reported in [illegible] 5 and 6 as cum[illegible]

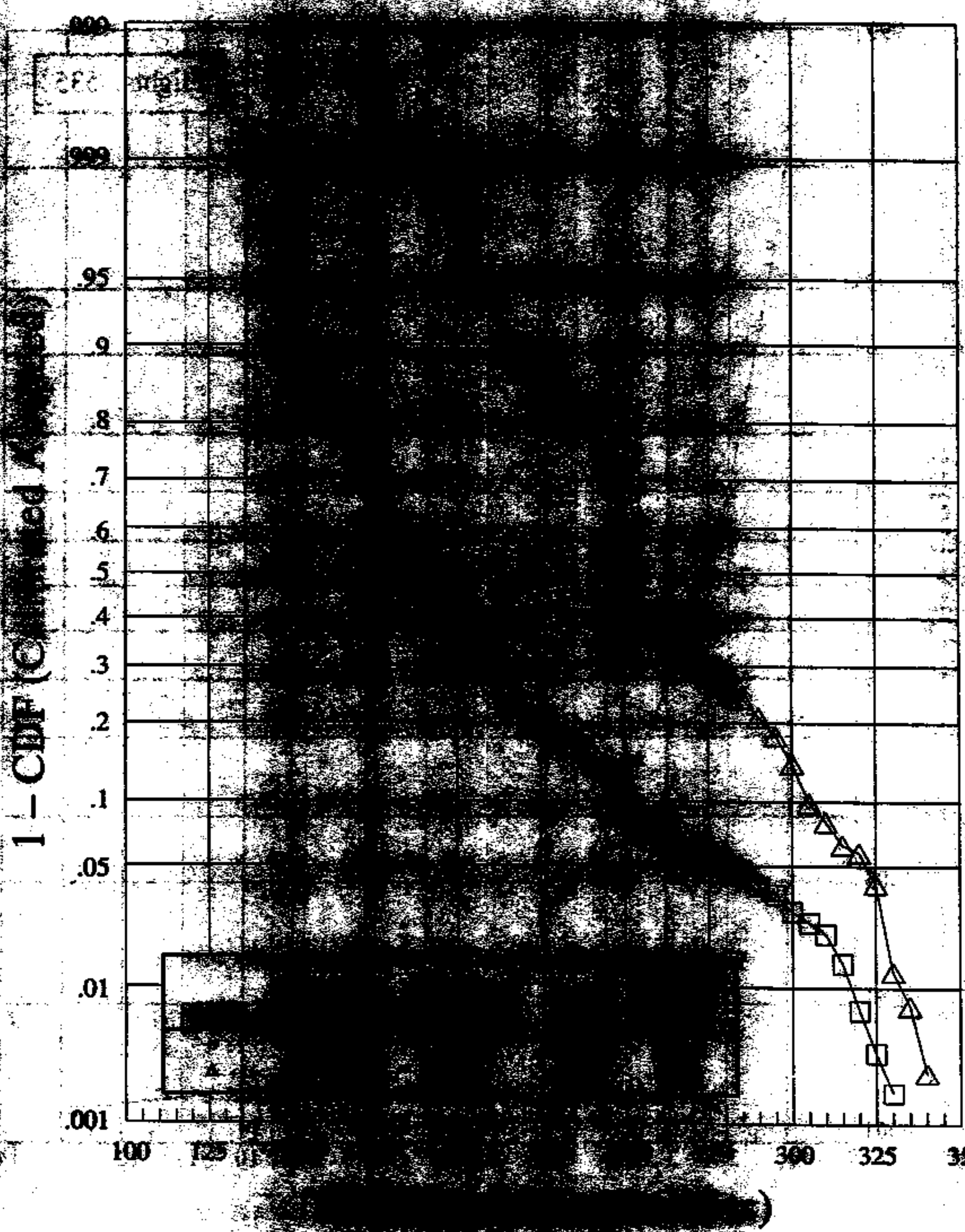


FIGURE [illegible] AIRSPEED
[illegible]

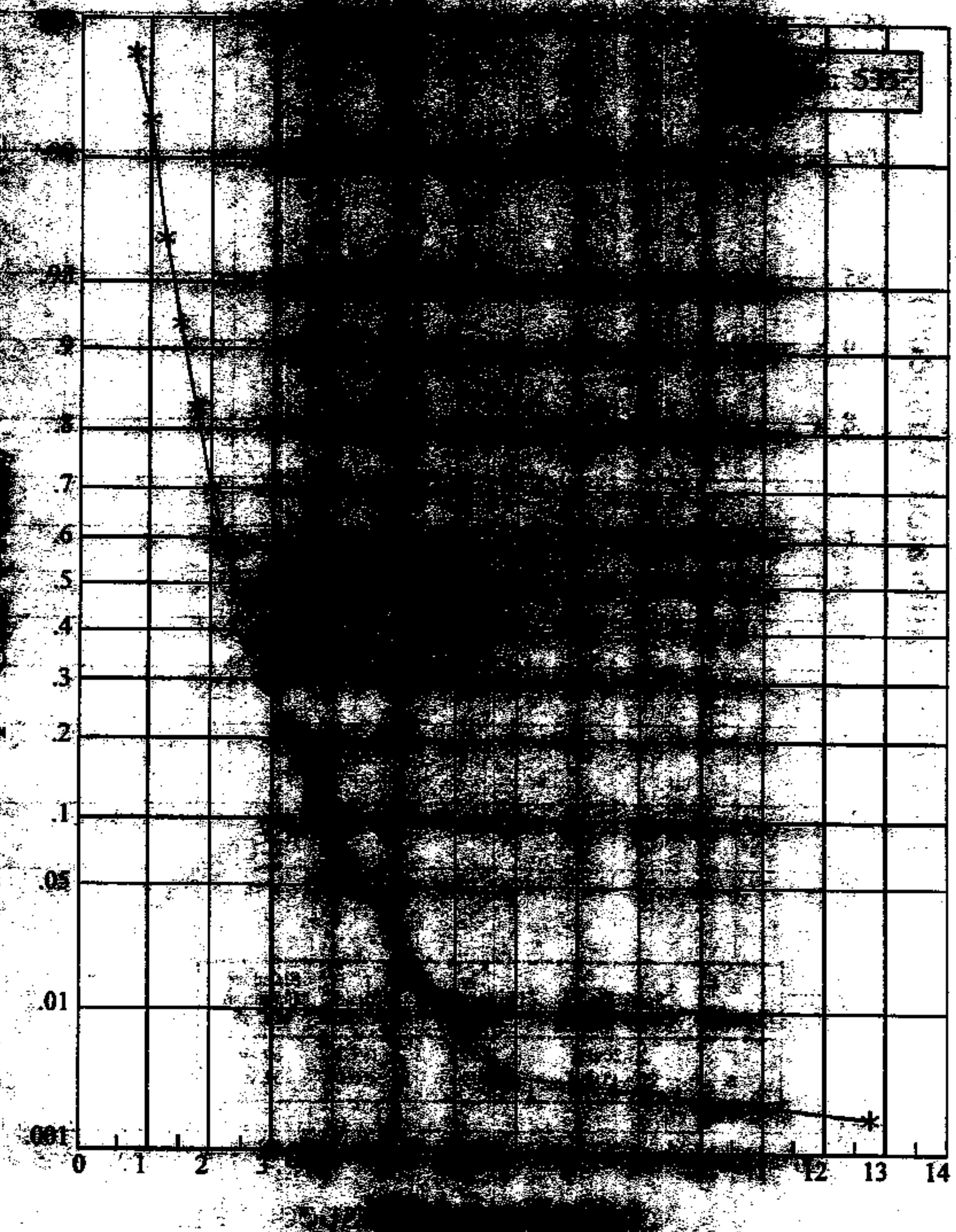


FIGURE 28. [illegible] MINUTES
[illegible]

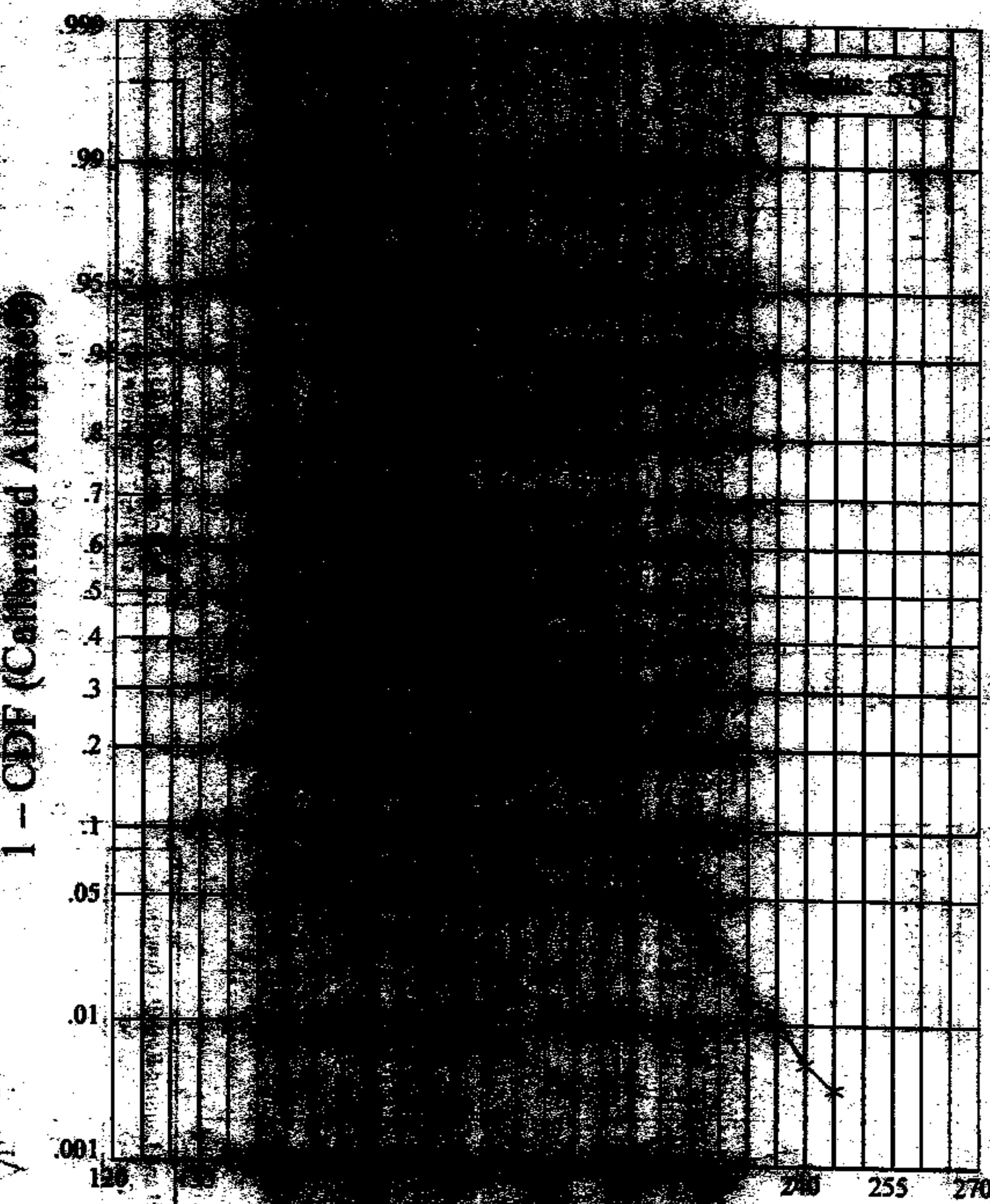


FIGURE [illegible] AIRSPEED

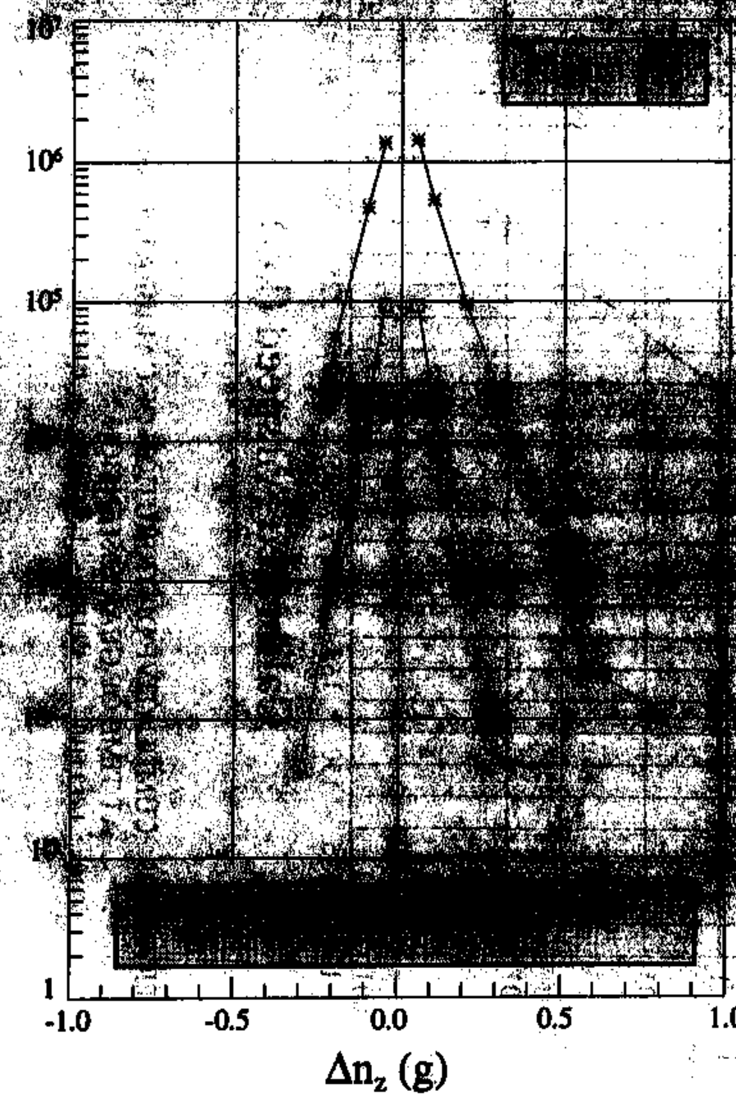


FIGURE 30. INCREMENTAL LOAD FACTOR CUMULATIVE OCCURRENCES PER 1000 HOURS BY [illegible] ROLL

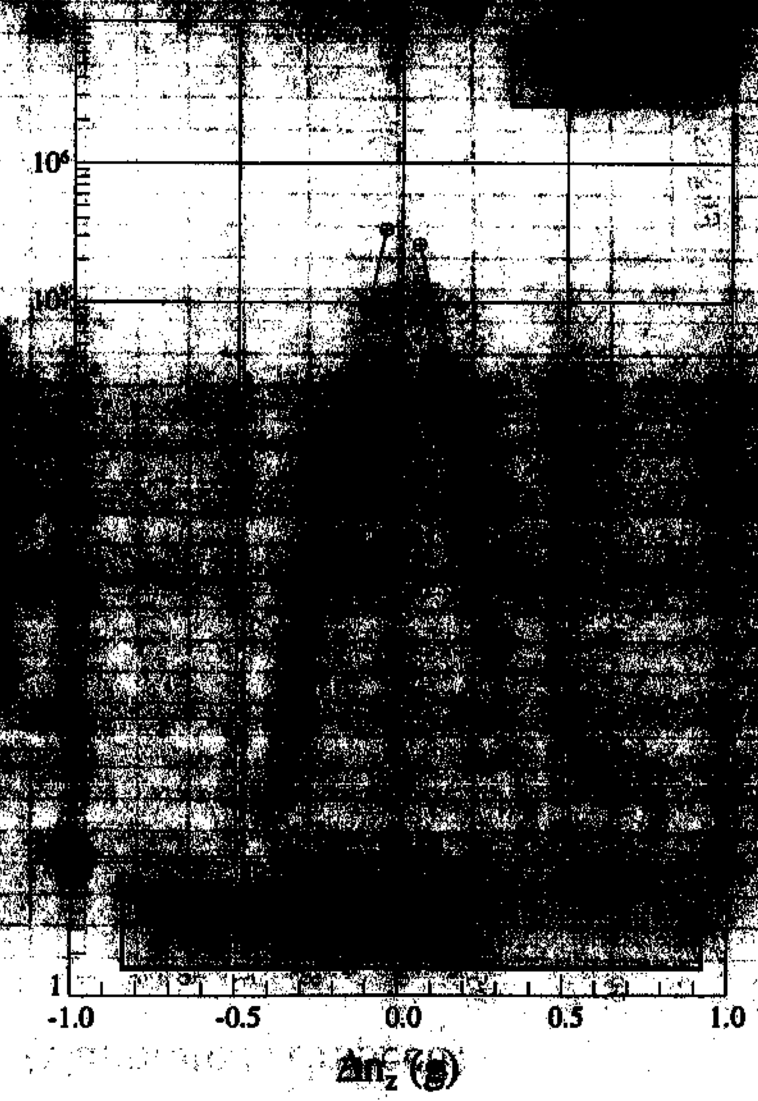


FIGURE 31. INCREMENTAL LOAD FACTOR CUMULATIVE OCCURRENCES PER [illegible]

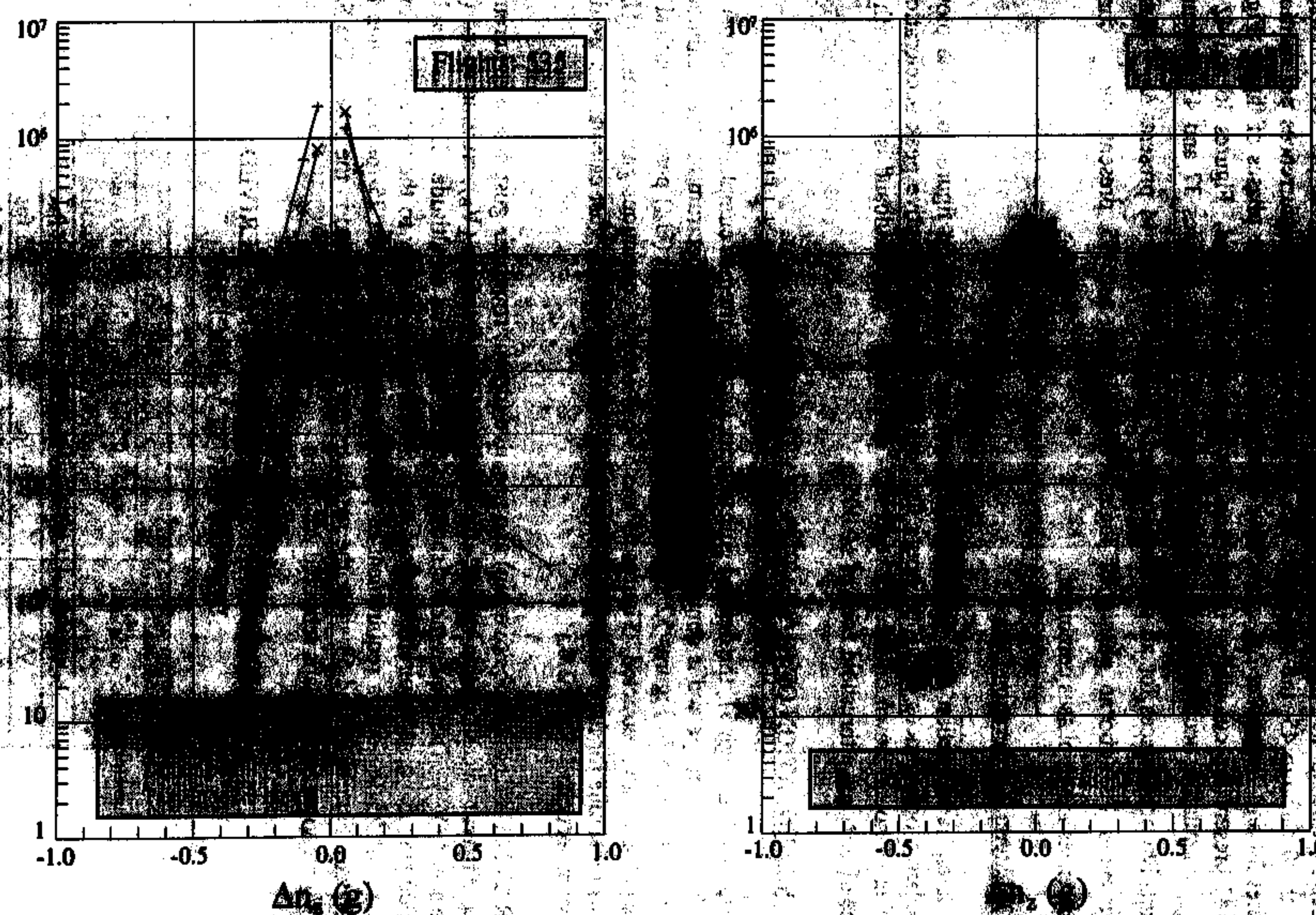


FIGURE 38.

[illegible] data for [illegible] two ways. [illegible] hours, and [illegible] Figures 35 [illegible] 36 and 42 present [illegible] 43 present $\Delta n_{z_{max}}$ [illegible] $\Delta n_{z_{max}}$ cumulative [illegible] by airline [illegible] $\Delta n_{z_{max}}$ cumulative [illegible] for all phases [illegible]

[illegible] acceleration [illegible] 46. The plot shows [illegible] occurrences [illegible] accelerations. The [illegible] hours shown [illegible] 0.01 g with a mean [illegible] and altitude [illegible]

[illegible] PRESENTATION OF [illegible]

[illegible] 47 through 51, [illegible] counts per nautical [illegible] altitude range [illegible] altitude ranges [illegible] in reference 7. [illegible] per nautical mile for [illegible] extended and retracted [illegible] intensity (U_{de}) peaks [illegible] nautical mile for flaps [illegible] are described [illegible] in sections 3.5 and 3.6.

[illegible] 25.341 establishes [illegible] design requirements for [illegible] different aircraft [illegible] speed (V_C) and [illegible] speed (V_D). The [illegible] between sea level and [illegible] feet, the gust [illegible] given for 50,000 [illegible] FAR 25.345 sets a [illegible] gusts when flaps are [illegible] Figures 52 and [illegible] FAR. The FAR limit [illegible] is shown for the flaps [illegible]

TABLE [illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
V_C [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
V_D [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Flaps [illegible]	[illegible]	[illegible]	[illegible]	[illegible]

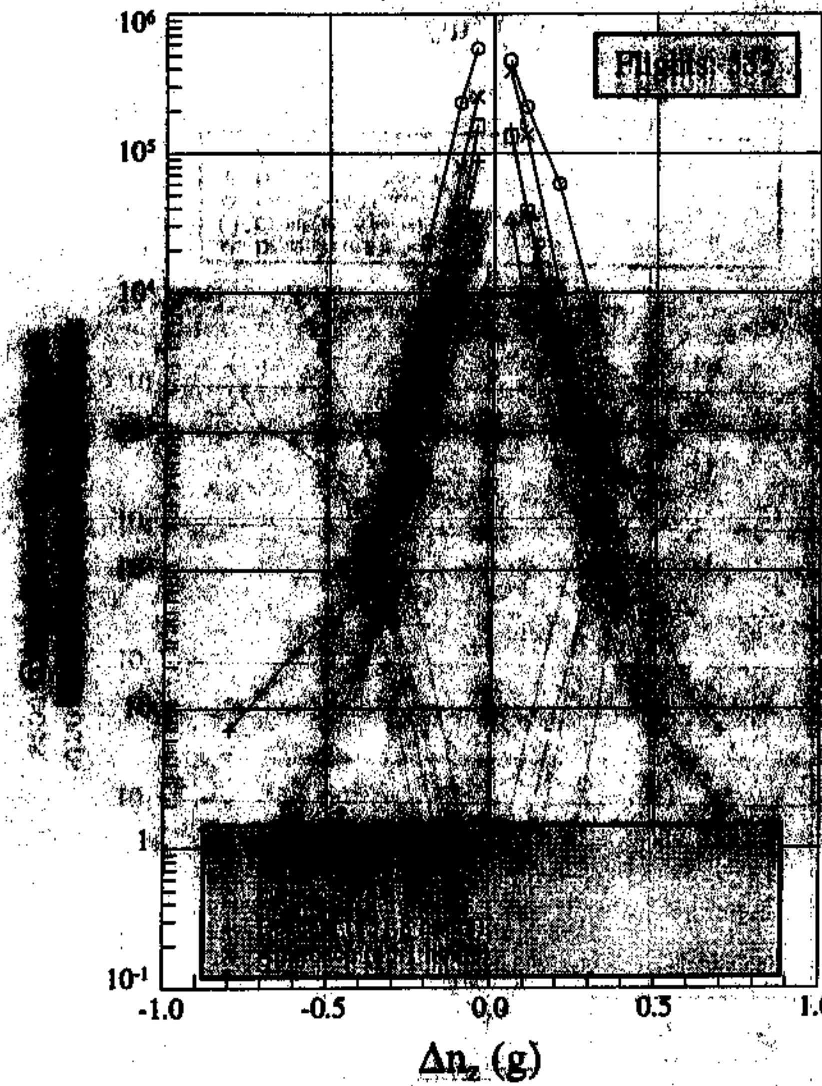


FIGURE 34. INCREMENTAL LOAD FACTOR

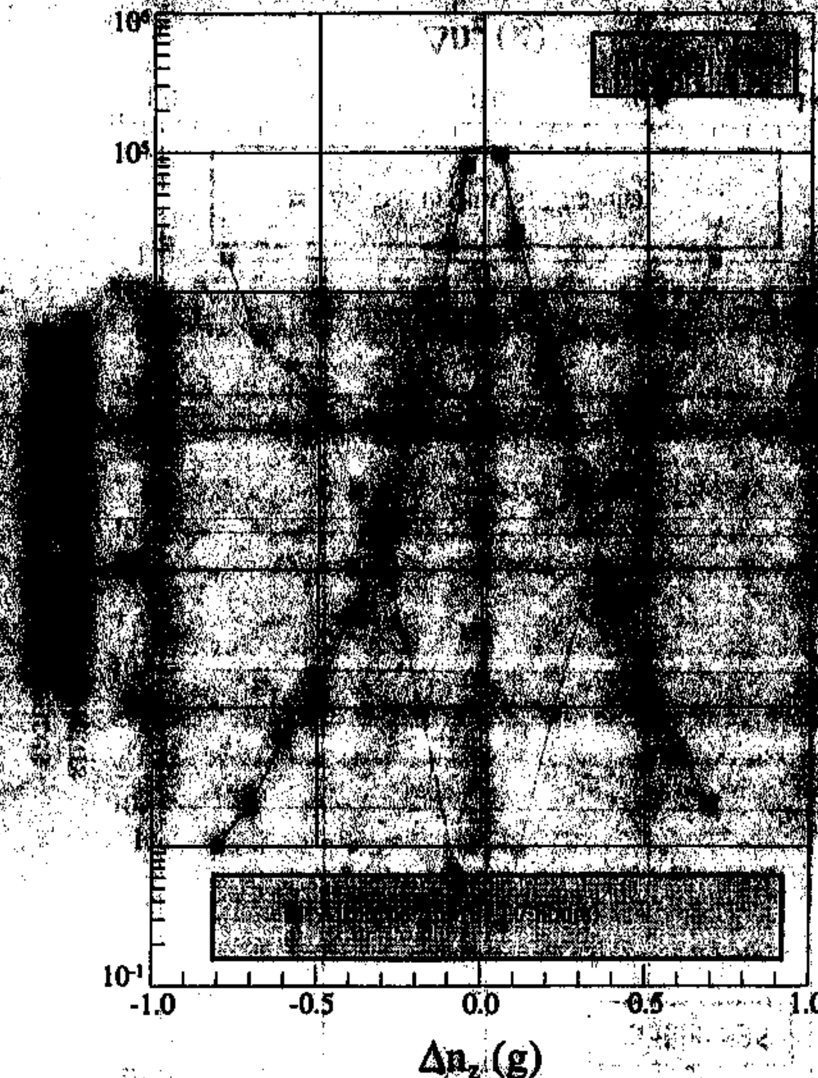


FIGURE 35. [illegible]

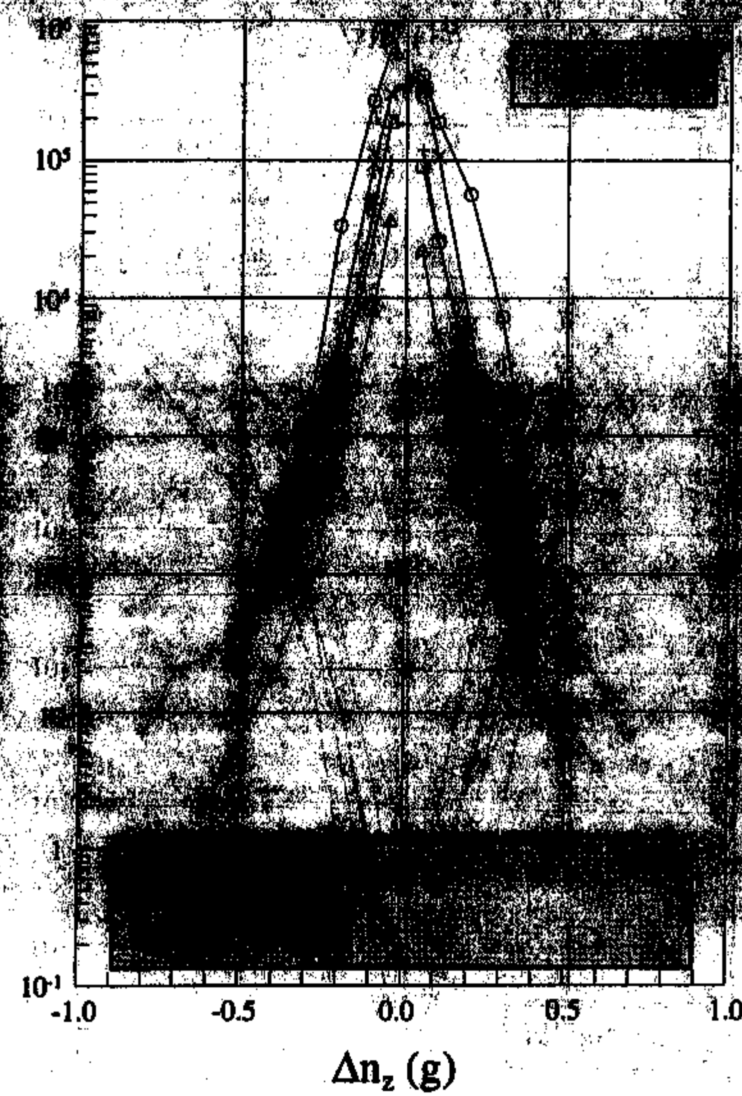


FIGURE 36. INCREMENTAL GUST LOAD FACTOR CUMULATIVE OCCURRENCES PER [illegible] BY AIRBORNE PHASE [illegible]

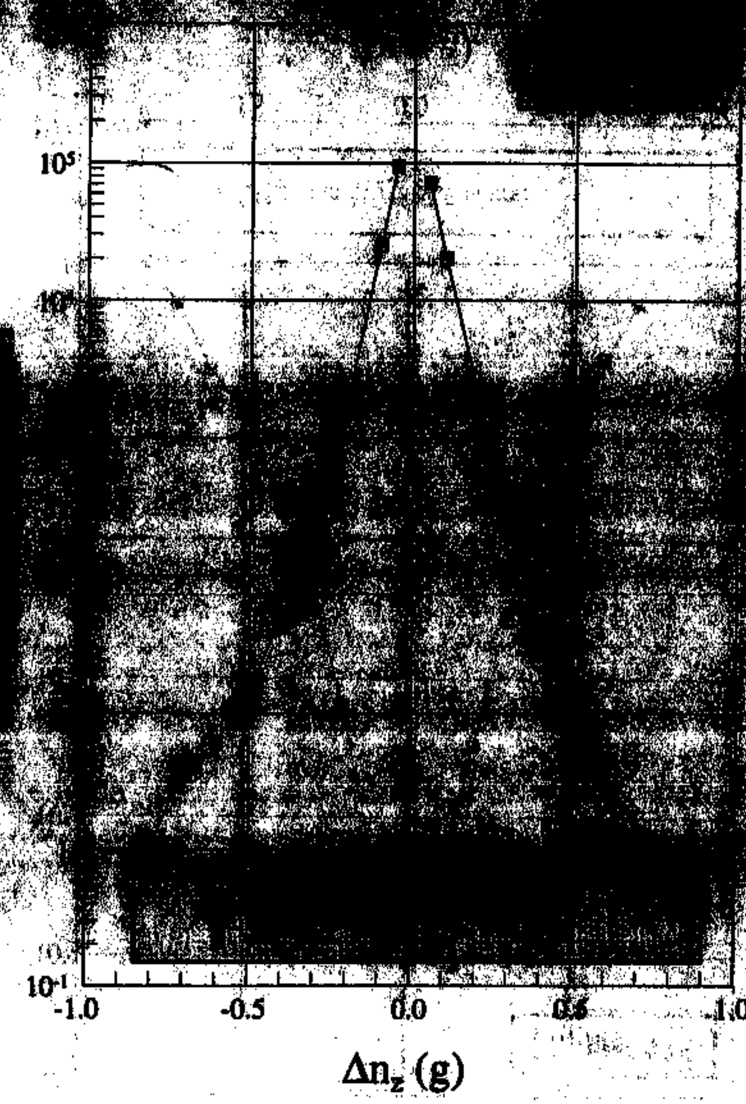
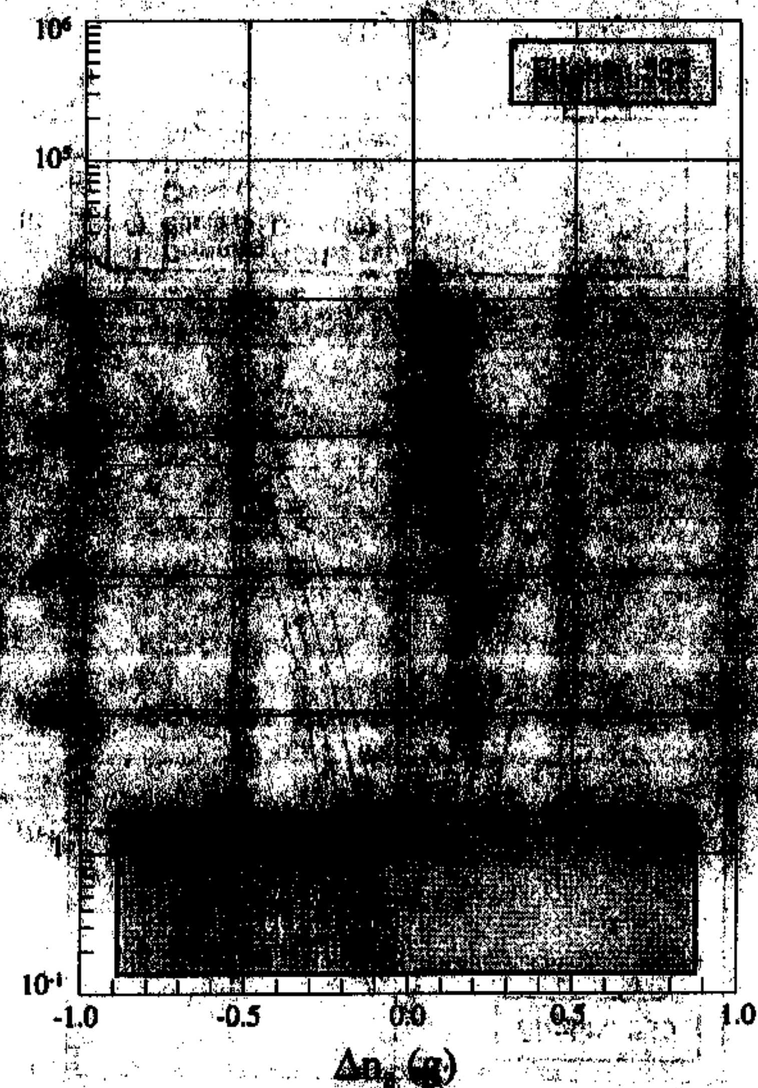
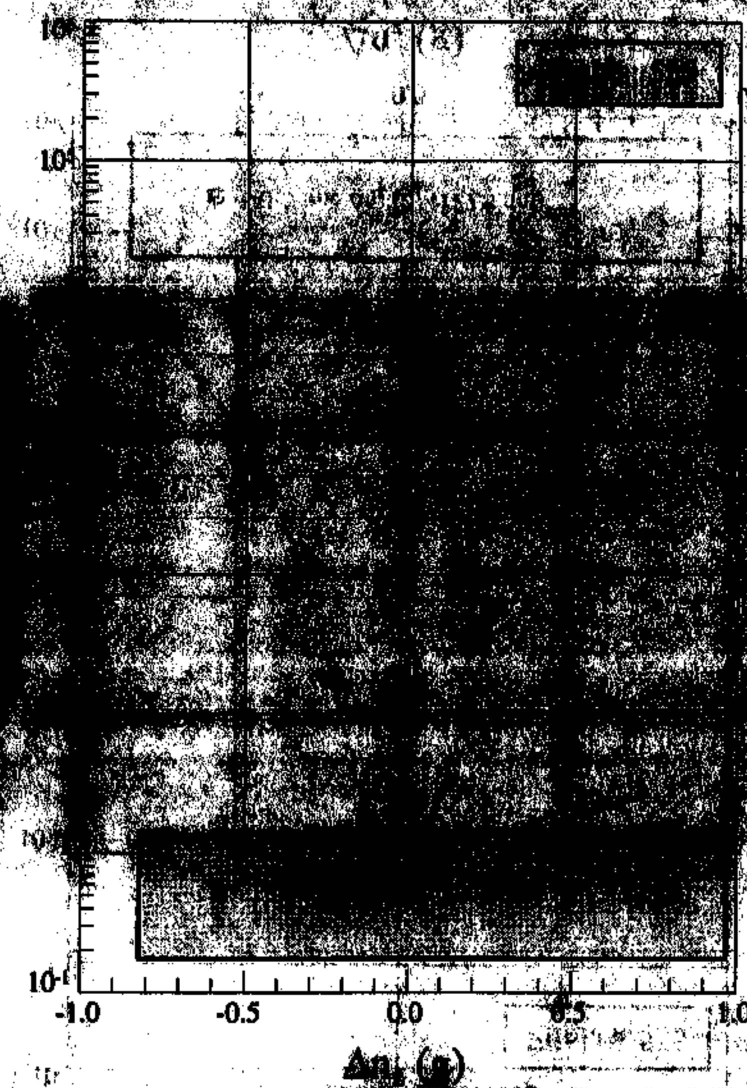


FIGURE 37. AIRBORNE INCREMENTAL GUST [illegible]


10⁶
10⁵
10⁻¹
-1.0
-0.5
0.0
0.5
1.0
Δn


10⁶
10⁵
10⁻¹
-1.0
-0.5
0.0
0.5
1.0
Δn

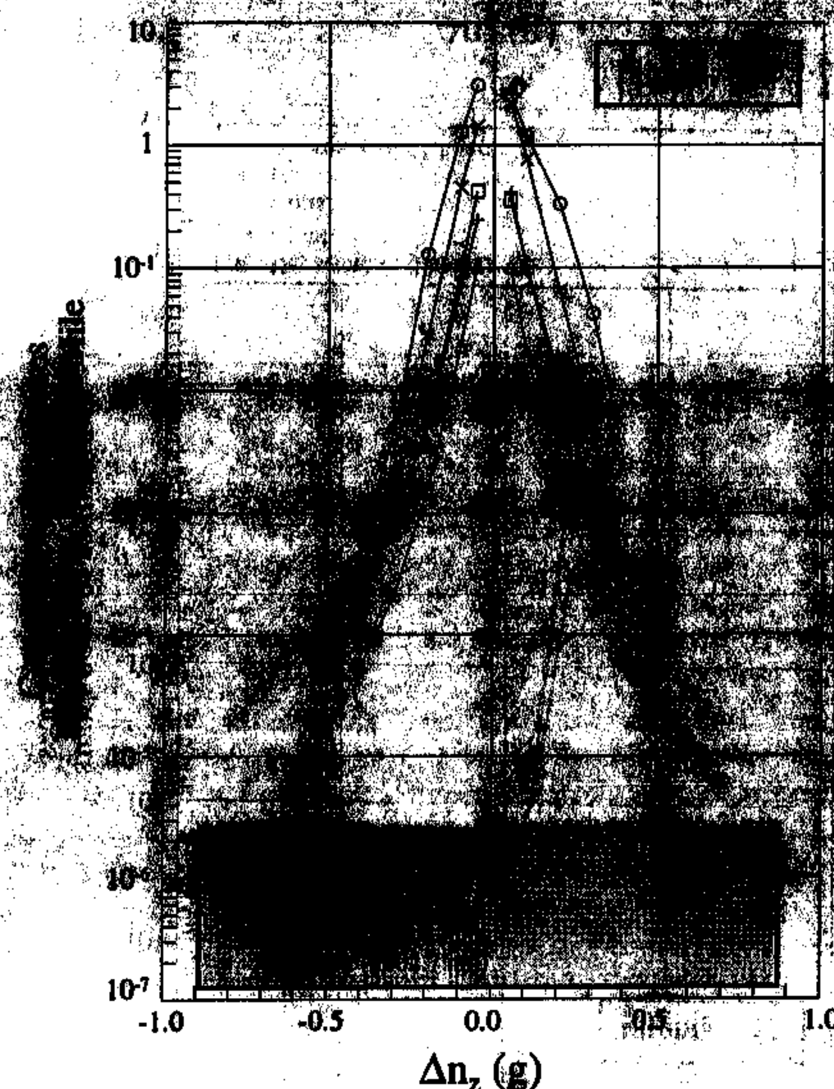


FIGURE 40. INCREMENTAL LOAD FACTOR CUMULATIVE OCCURRENCES PER NAUTICAL MILE BY AIRBORNE PHASE OF FLIGHT

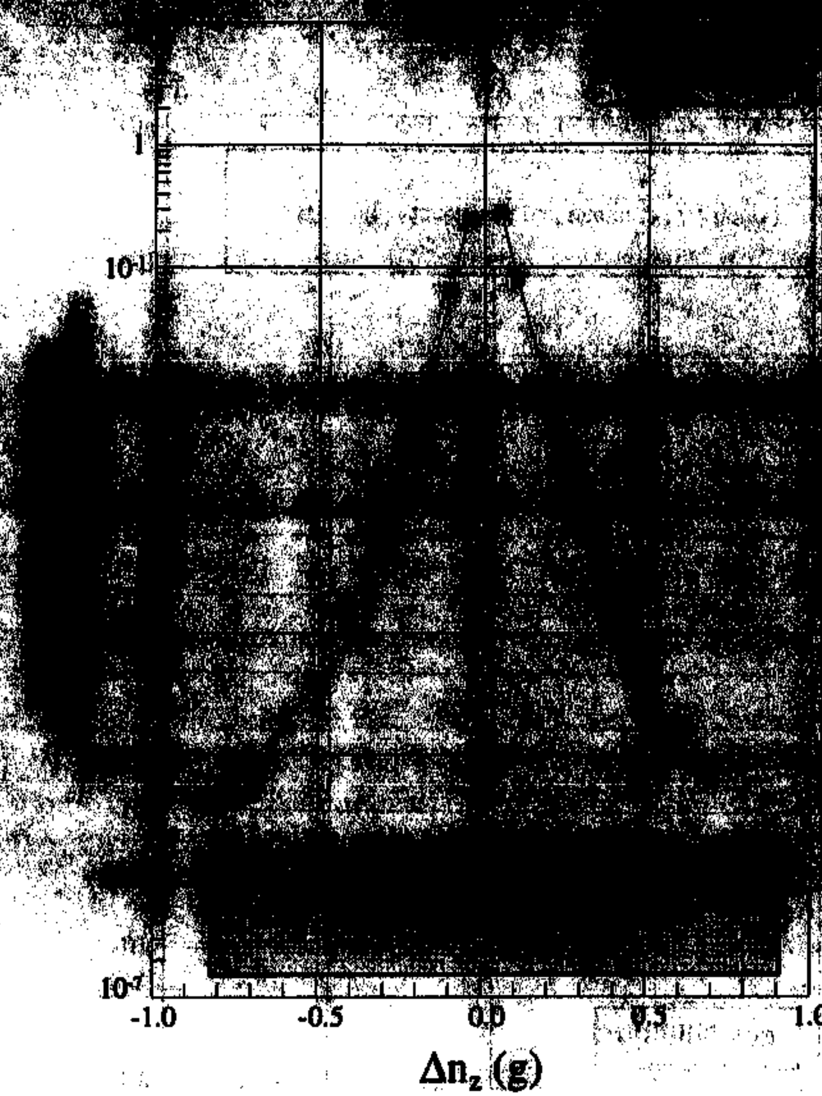
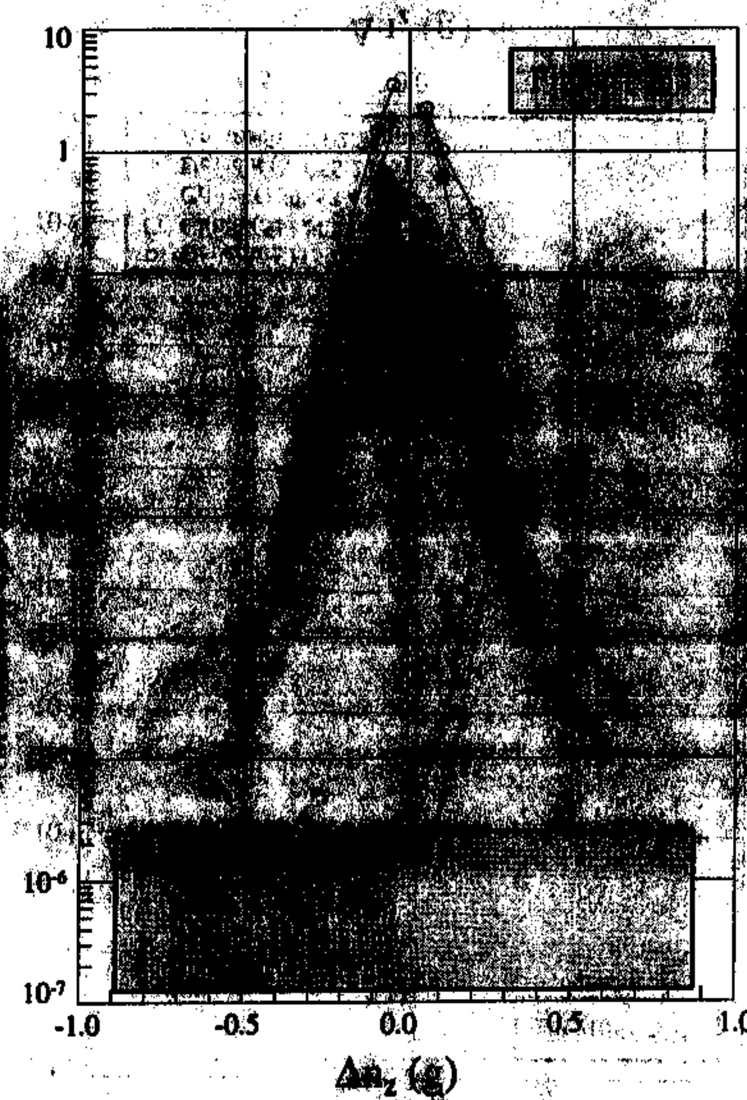
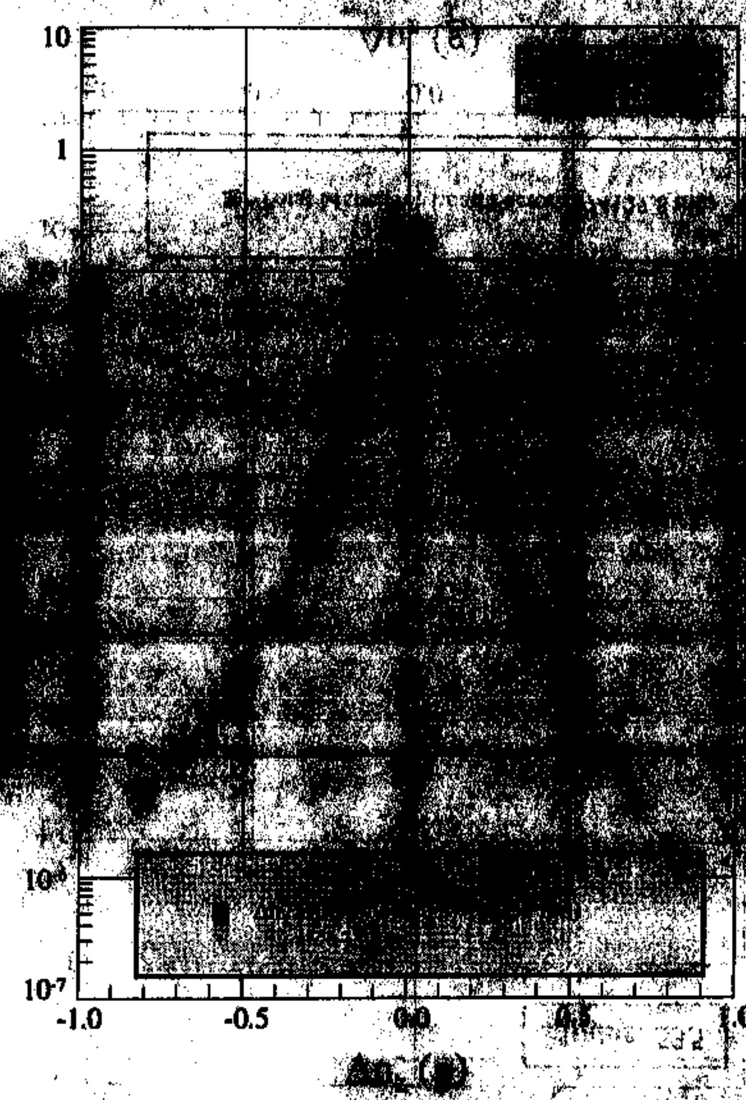


FIGURE 41. AIRBORNE INCREMENTAL LOAD FACTOR CUMULATIVE OCCURRENCES PER [illegible]


10
1
10^{-6}
10^{-7}
-1.0
-0.5
0.0
0.5
1.0
Δn_z (g)


10
1
10^{-7}
-1.0
-0.5
0.0
0.5
1.0

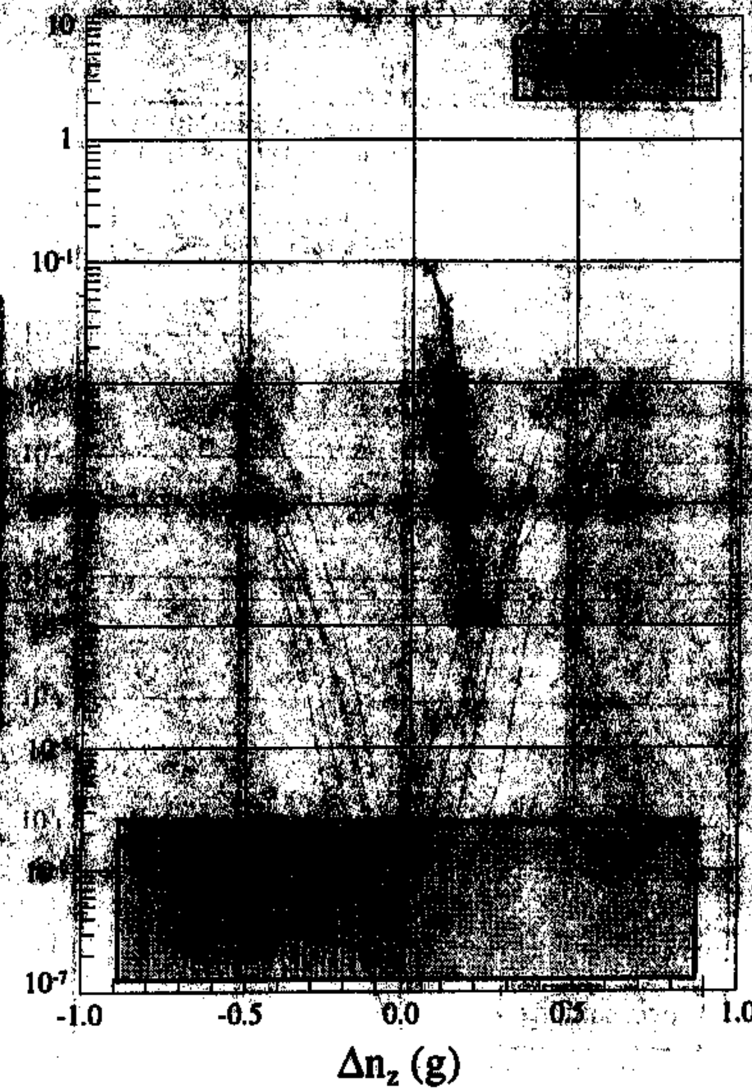


FIGURE 44. INCREMENTAL MANEUVER LOAD FACTOR CUMULATIVE OCCURRENCES PER NAUTICAL MILE BY AIRBORNE PHASE OF FLIGHT

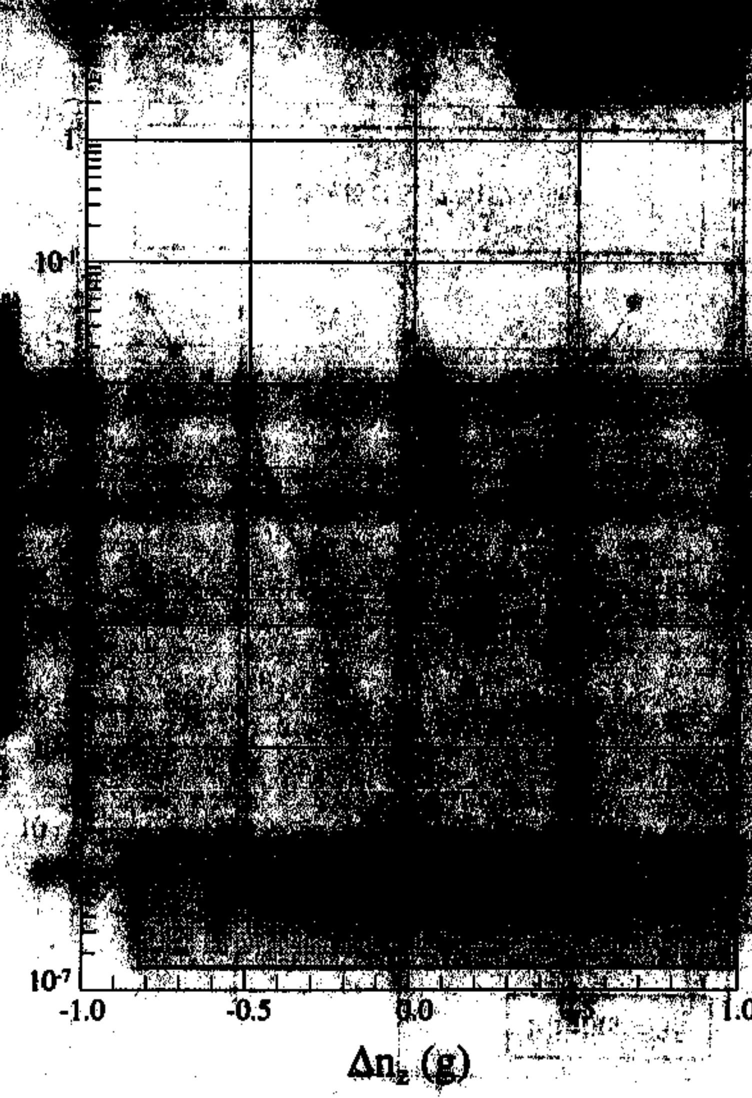


FIGURE 45. INCREMENTAL MANEUVER LOAD FACTOR CUMULATIVE OCCURRENCES PER NAUTICAL MILE

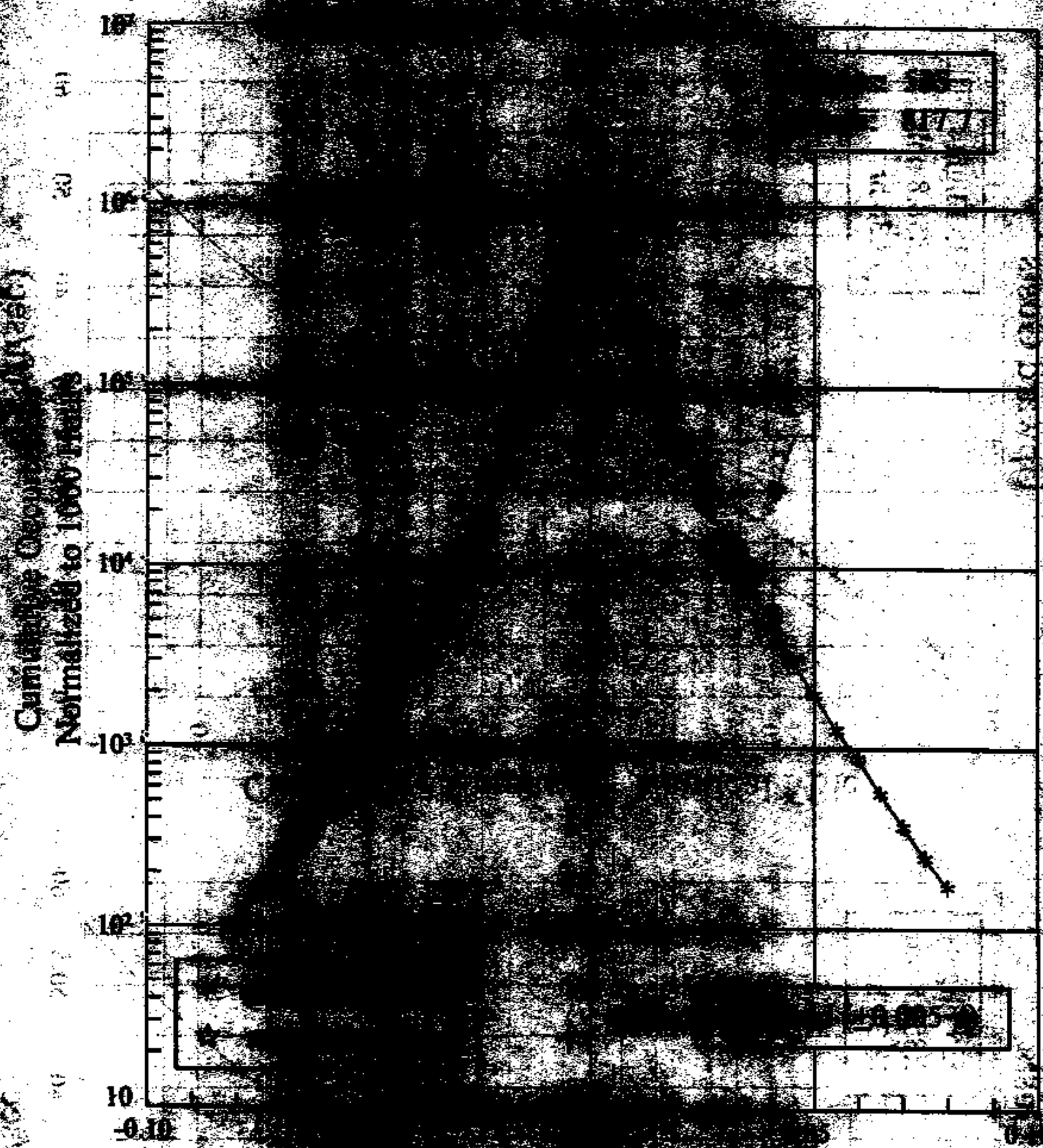


FIGURE 4Q [illegible] OCCURRENCES

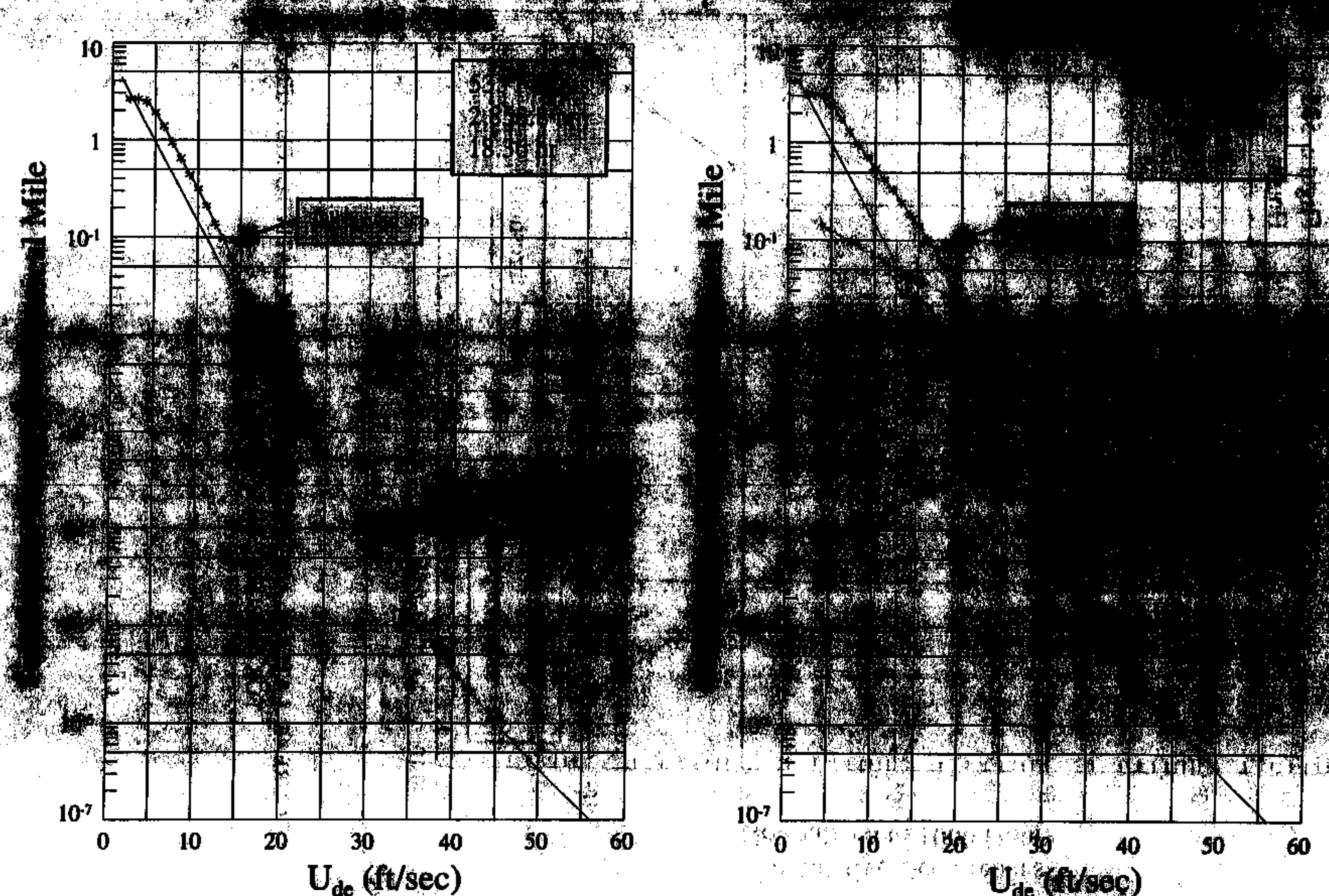
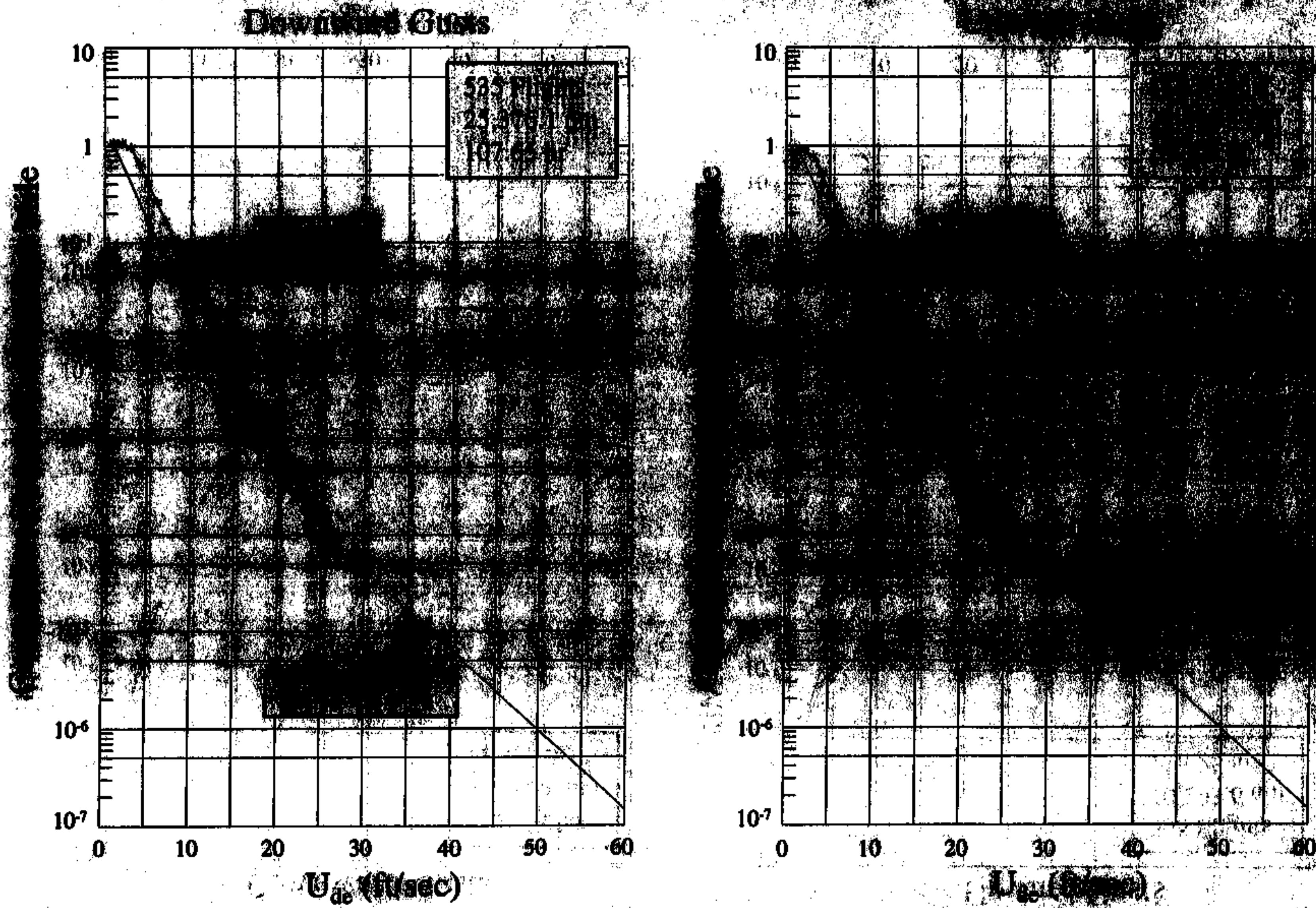


FIGURE 47. DERIVED GUST VELOCITY CUMULATIVE PEAK COUNTS PER NAUTICAL MILE (0-2000 FT)


Downward Gusts
535 Flights
10
1
10^{-6}
10^{-7}
0
10
20
30
40
50
60
U_{de} (ft/sec)

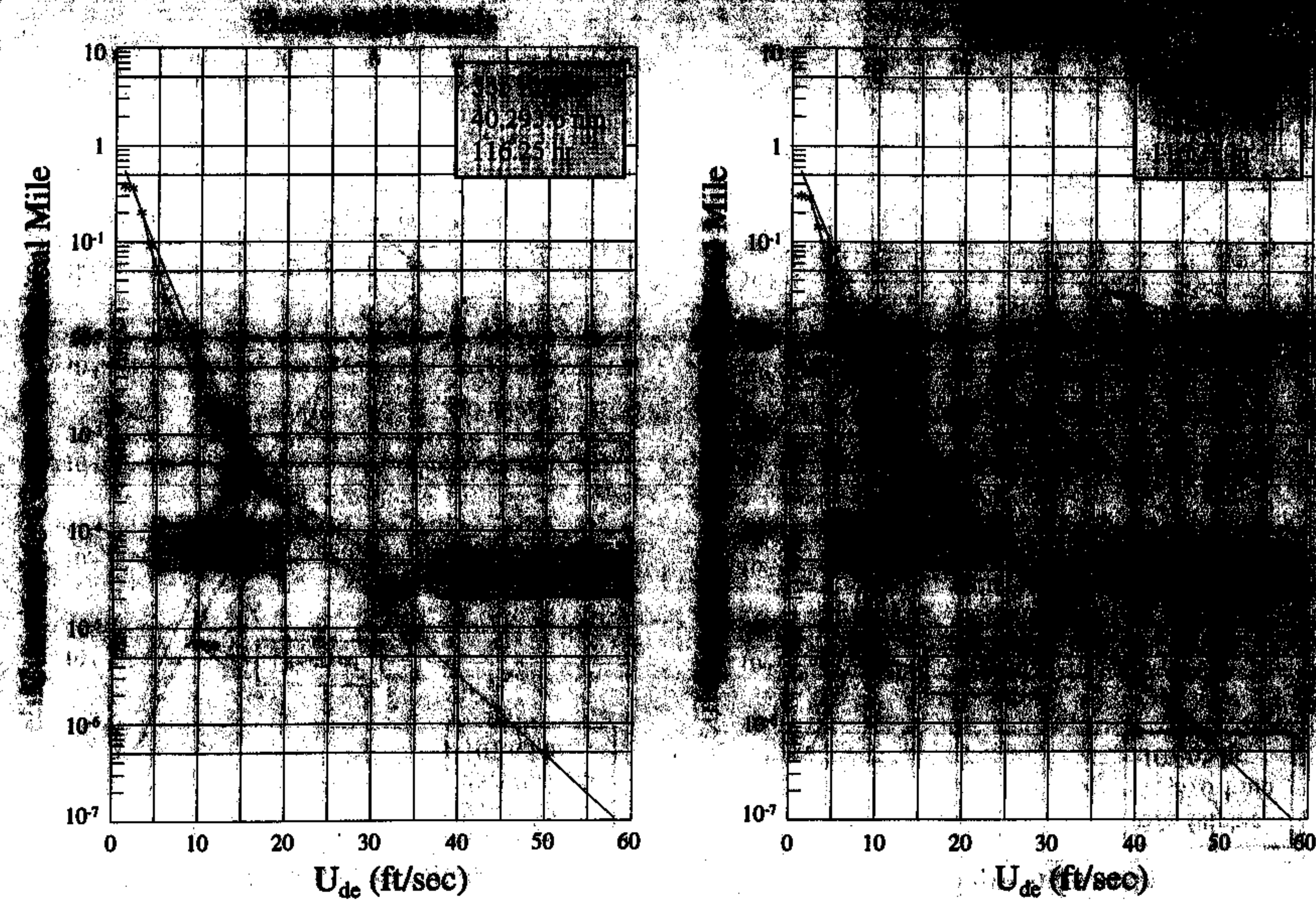
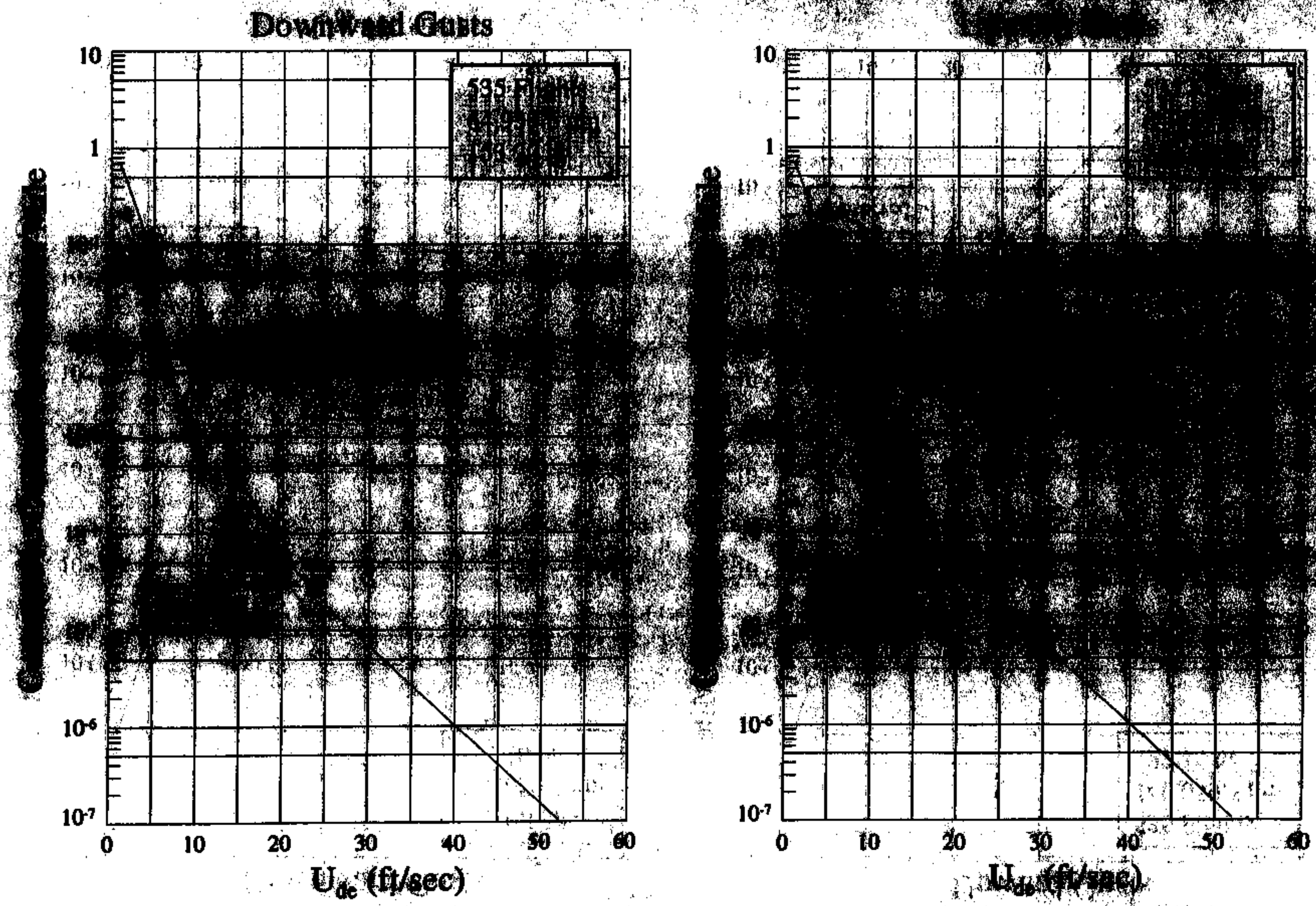


FIGURE 49. DERIVED GUST VELOCITY CUMULATIVE PEAK COUNTS PER NAUTICAL MILE (10,000-20,000 FT.)


Downward Gusts
10
1
10-6
10-7
0
10
20
30
40
50
60
U_de (ft/sec)

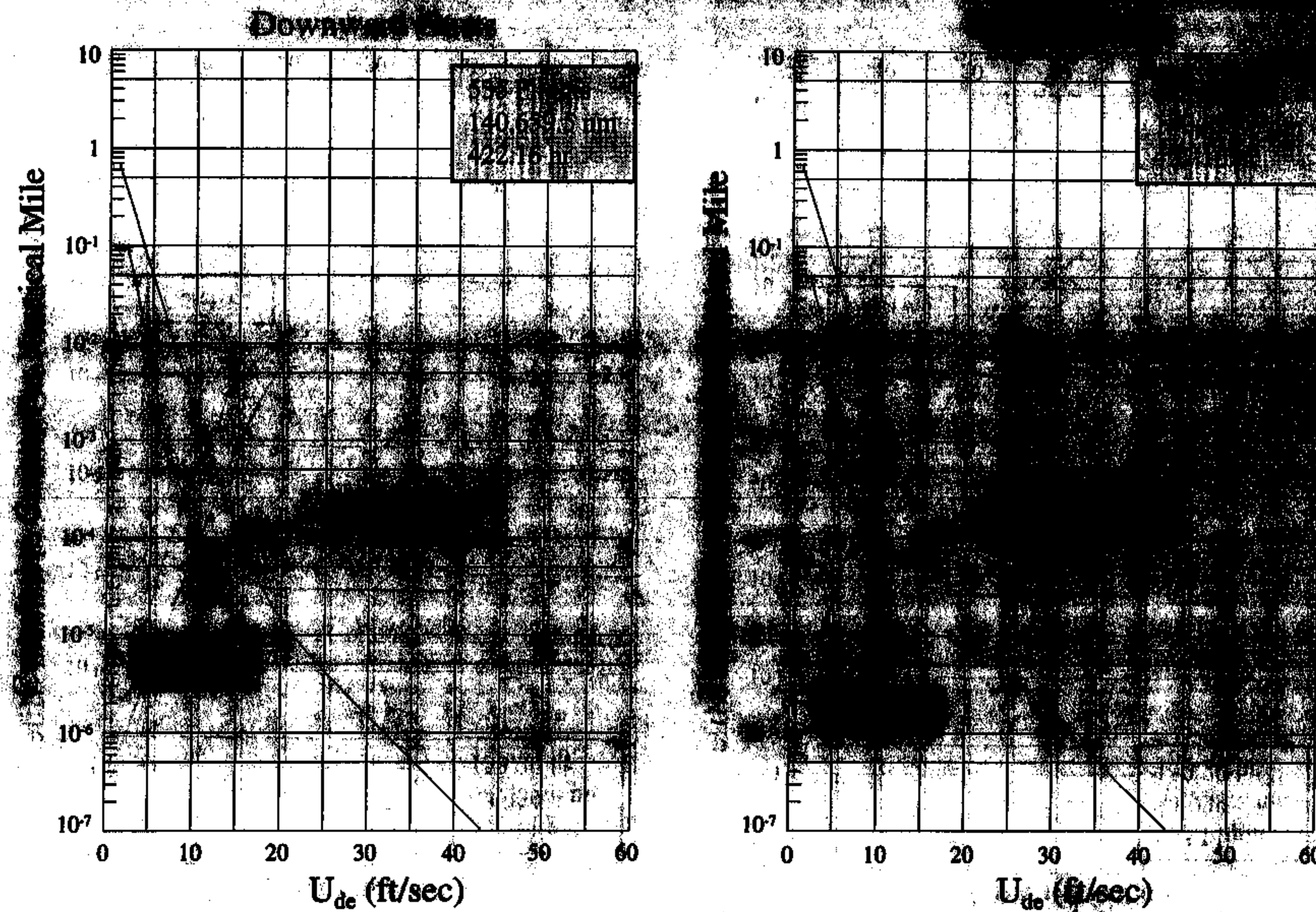


FIGURE 51. DERIVED GUST VELOCITY CUMULATIVE COUNTS PER NAUTICAL MILE (20,000-40,000 FT.)

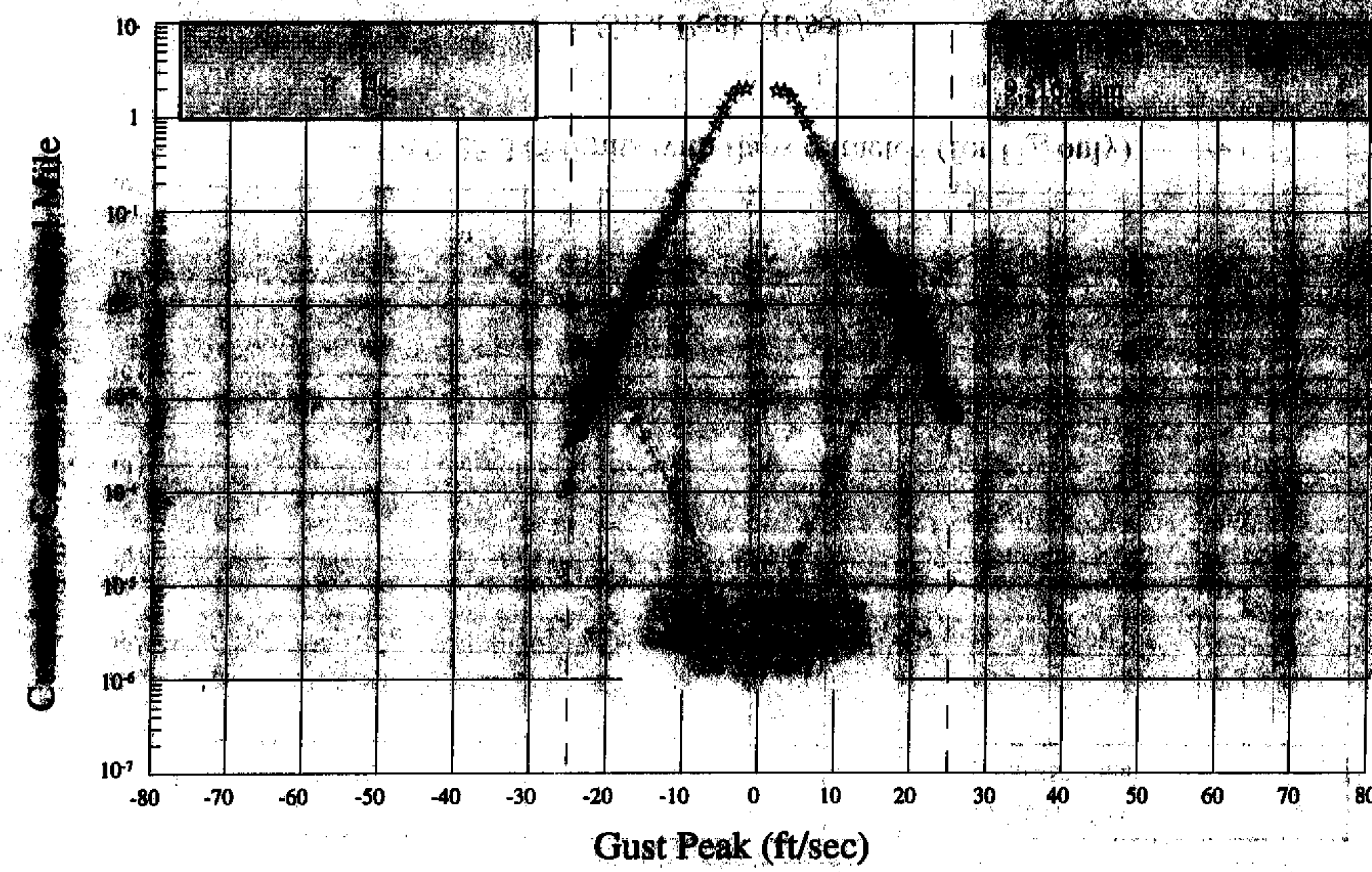


FIGURE 52. DISCRETE GUST CUMULATIVE PEAK COUNTS PER NAUTICAL MILE WITH FLAPS EXTENDED

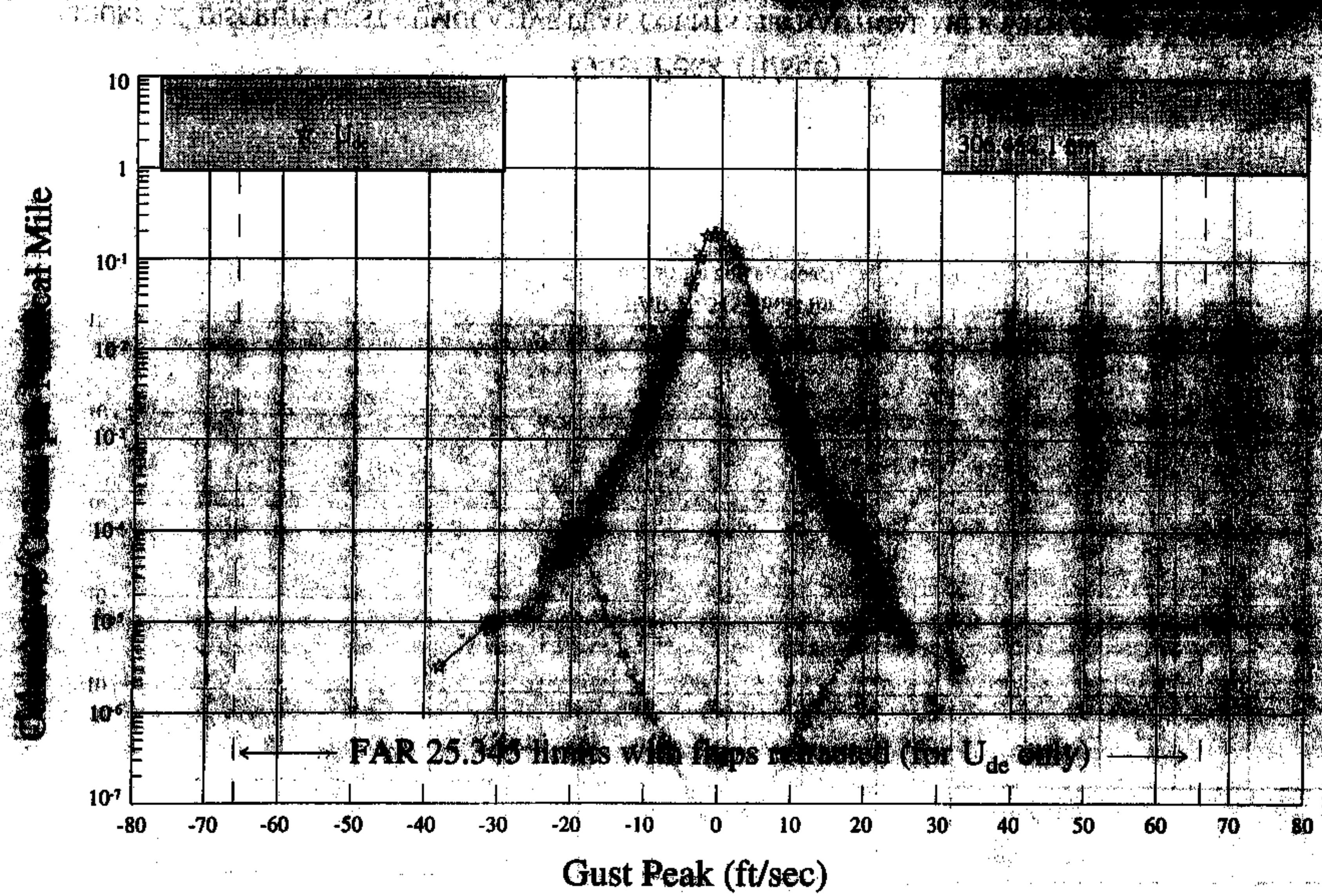


FIGURE 53. DISCRETE GUST CUMULATIVE PEAK COUNTS PER NAUTICAL MILE WITH FLAPS RETRACTED

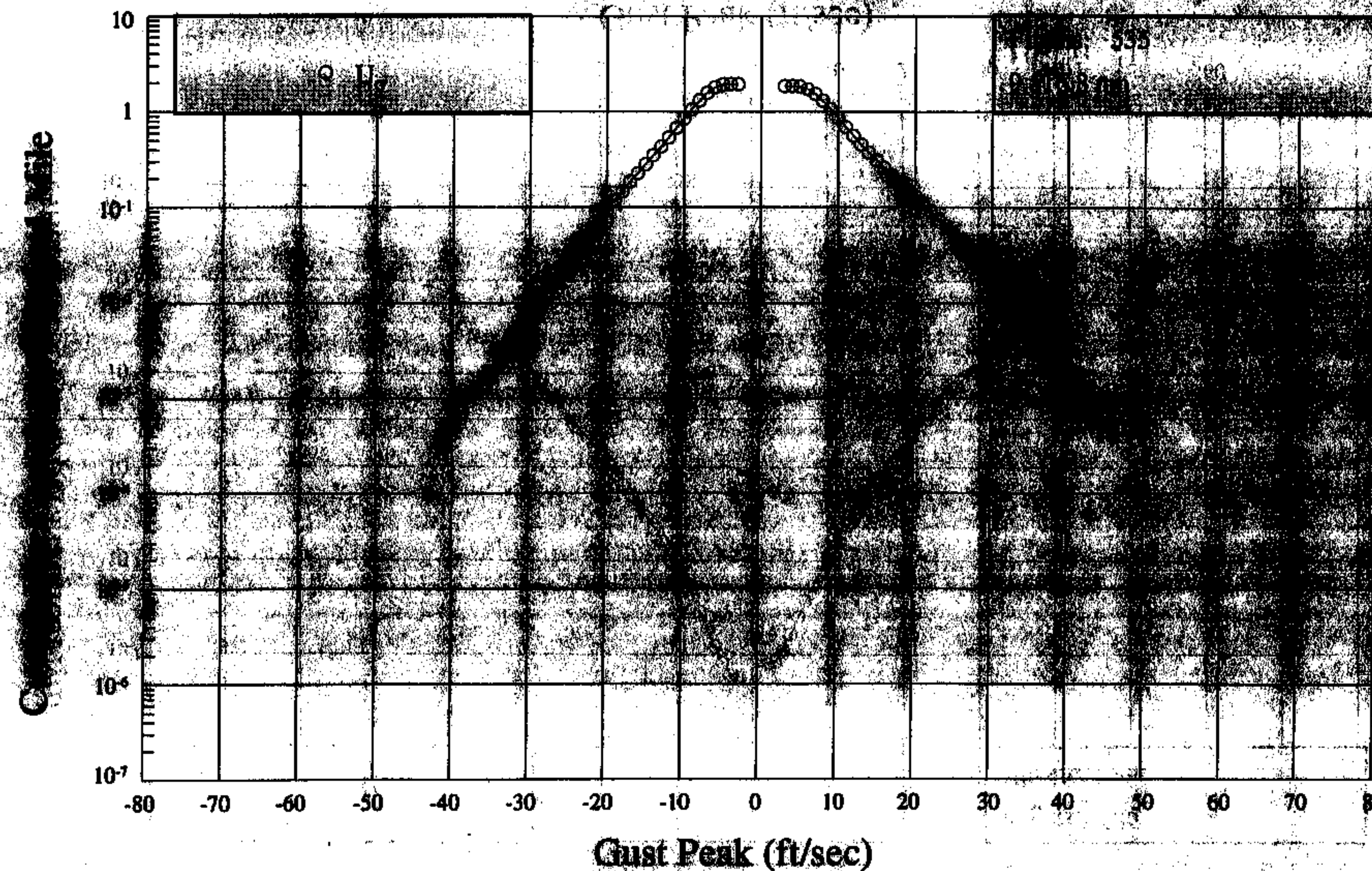


FIGURE 54. CONTINUOUS GUST CUMULATIVE PEAK COUNTS PER NAUTICAL MILE WITH FLAPS EXTENDED

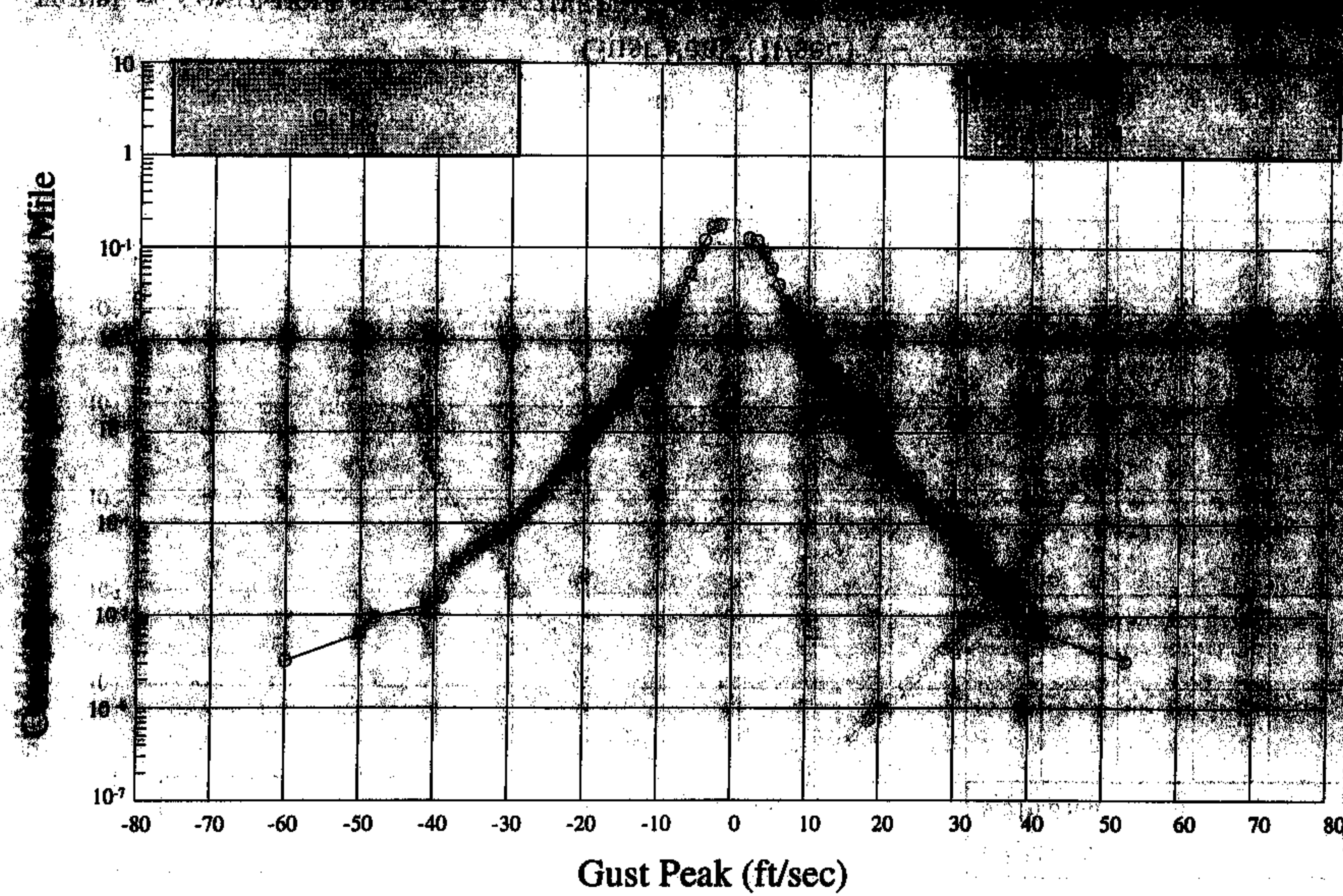


FIGURE 55. CONTINUOUS GUST CUMULATIVE PEAK COUNTS PER NAUTICAL MILE WITH FLAPS RETRACTED

[illegible] paragraph [illegible] a U_G value [illegible] linearly [illegible] is [illegible] in table 10.

[illegible] US

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible] airplane [illegible] satisfactory [illegible] the [illegible] 7-400 and similar [illegible] are [illegible]

T[illegible] UOUS

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

4.9 DEVELOP[illegible]

FAR 25.333 [illegible] be established at [illegible] combination of [illegible] of maneuvering and [illegible] load envelopes (V-[illegible] and normal [illegible] gust load factors, [illegible] from the FAR [illegible] figures 56 through [illegible]

The required limit load [illegible] 25.337. This states that the positive limit maneuver [illegible] and that the negative [illegible] maneuvering load factor [illegible] V_C, varying linearly with speed to zero at V_D. FAR [illegible] load factor is 2.0 g when the flaps are extended. The [illegible] The stall curve on the left side [illegible]

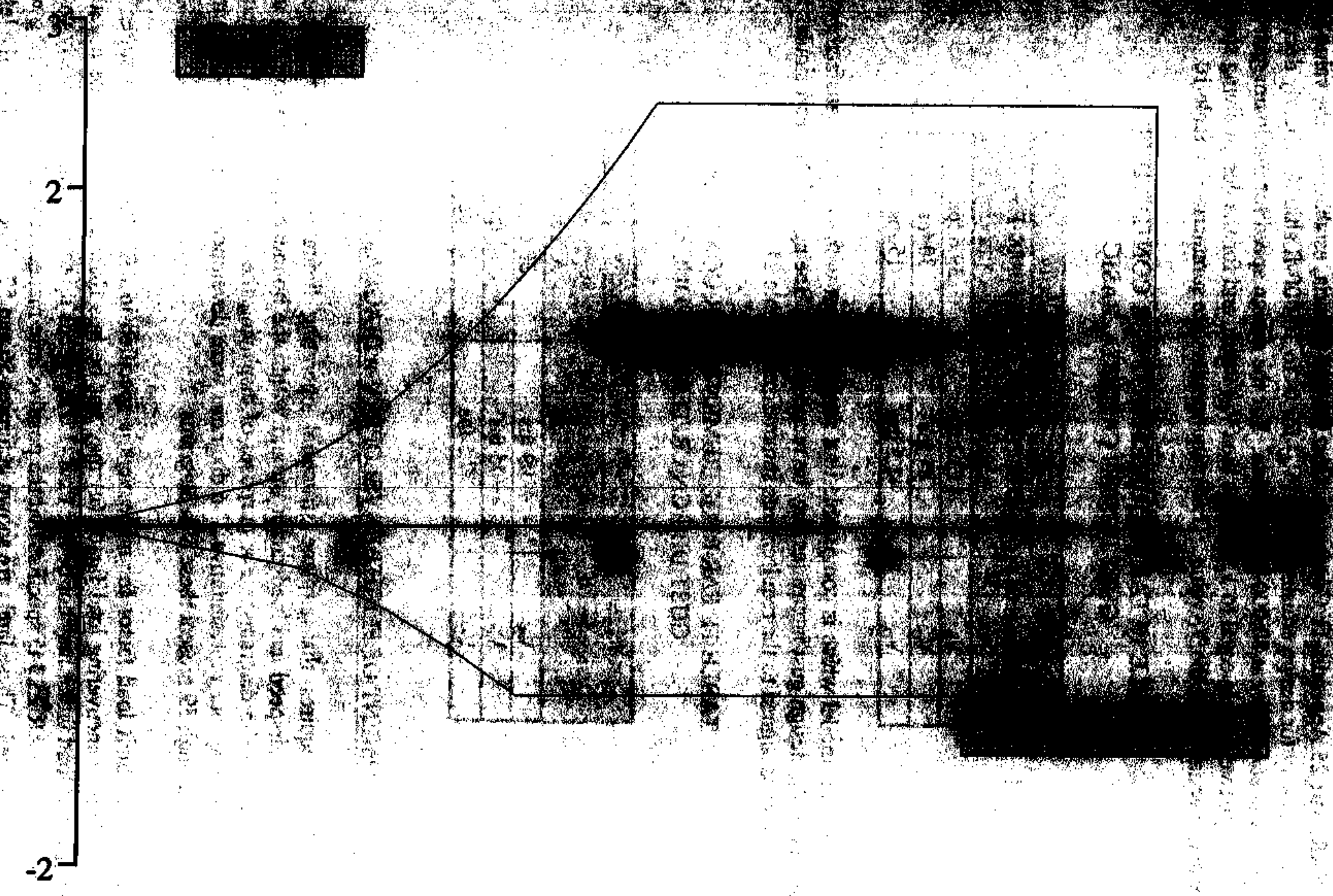
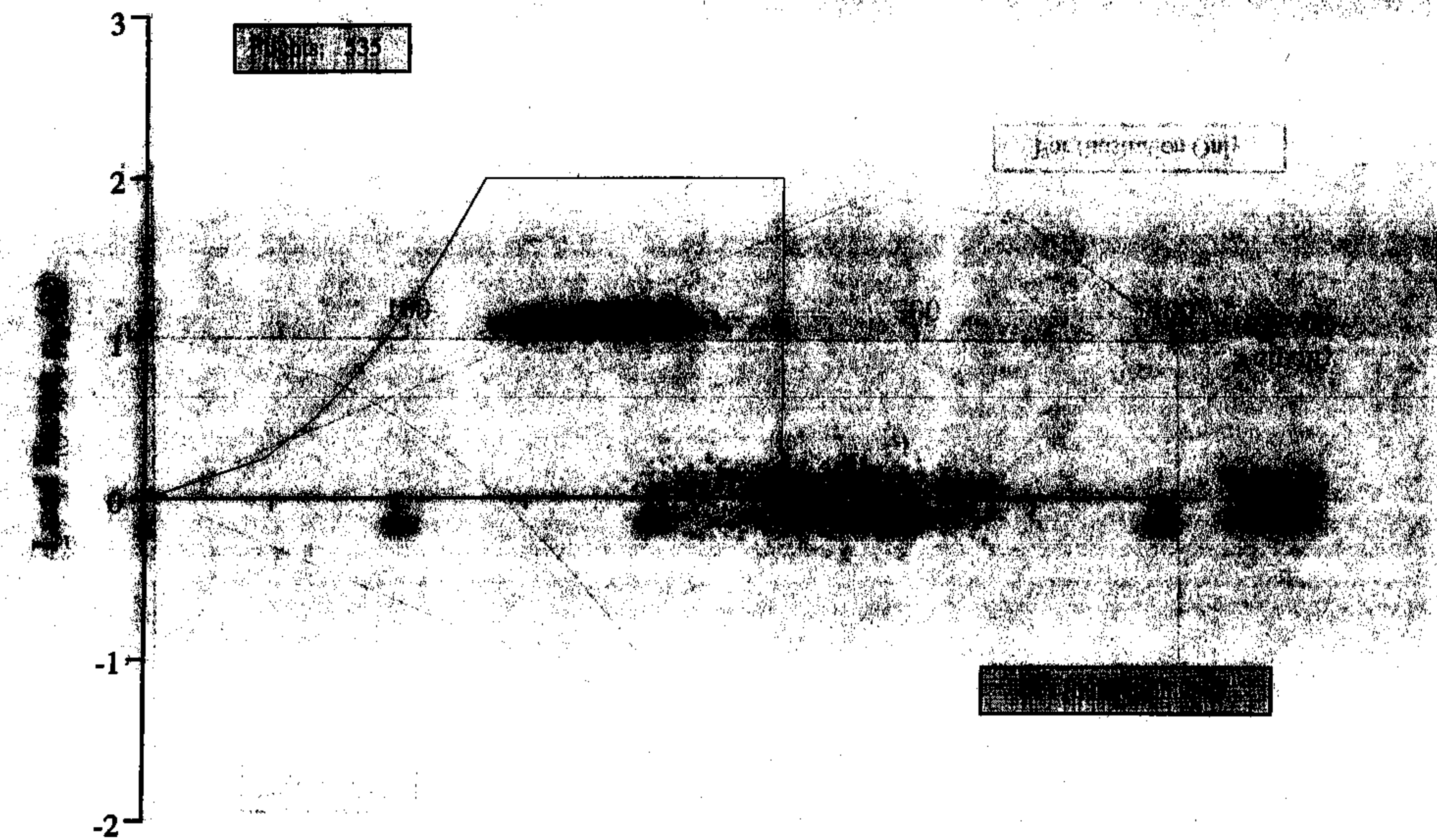


FIGURE 56. V-n DIAGRAM FOR MANEUVERS WITH FLAPS RETRACTED, PER FAR 25.333B


3
2
1
0
-1
-2

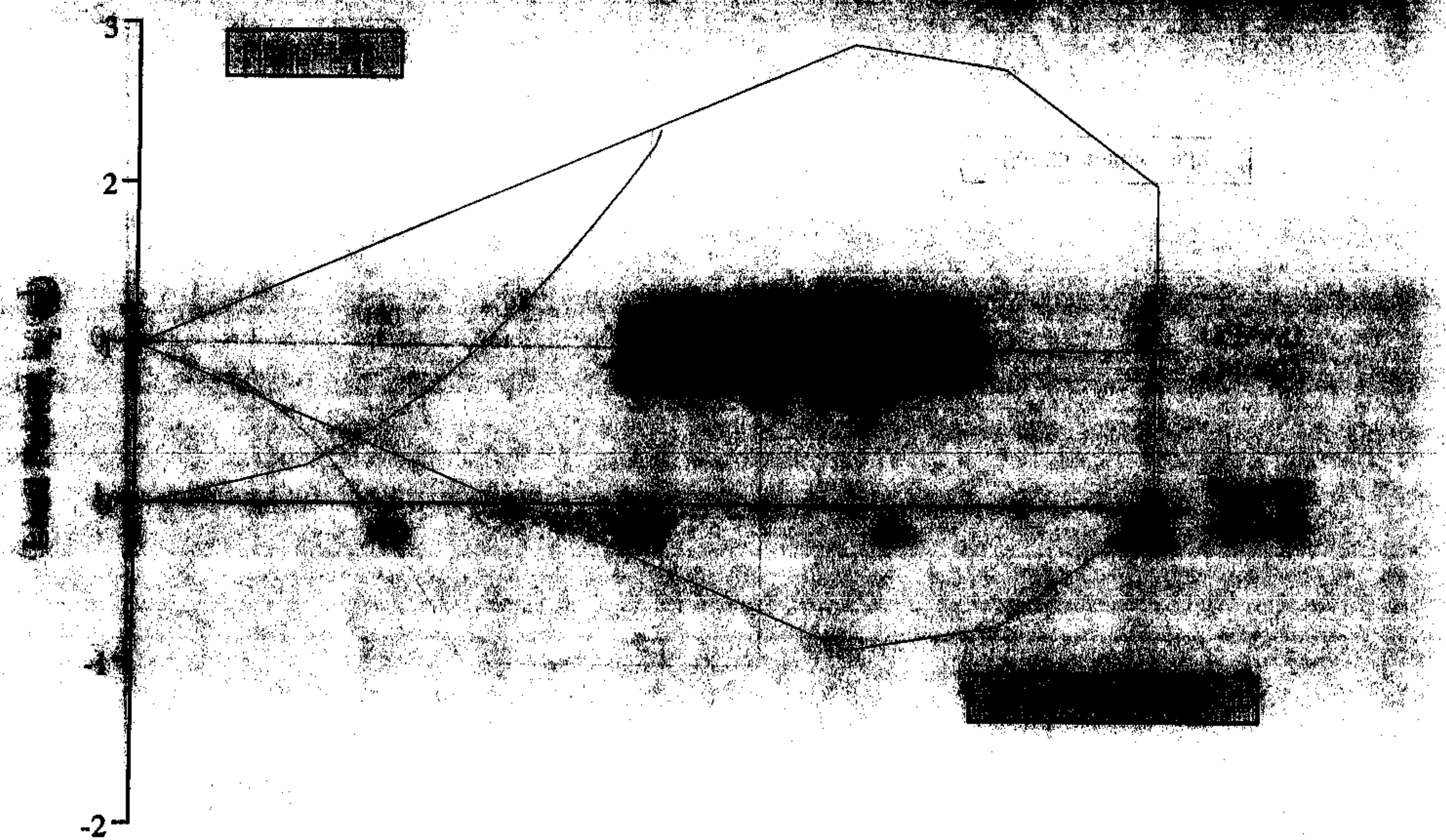


FIGURE 58. V-n DIAGRAM FOR GUSTS WITH FLAPS RETRACTED, PER FAR 25.333C

the envelopes is determined [illegible] curve was estimated by the 1 g stall speed in [illegible]

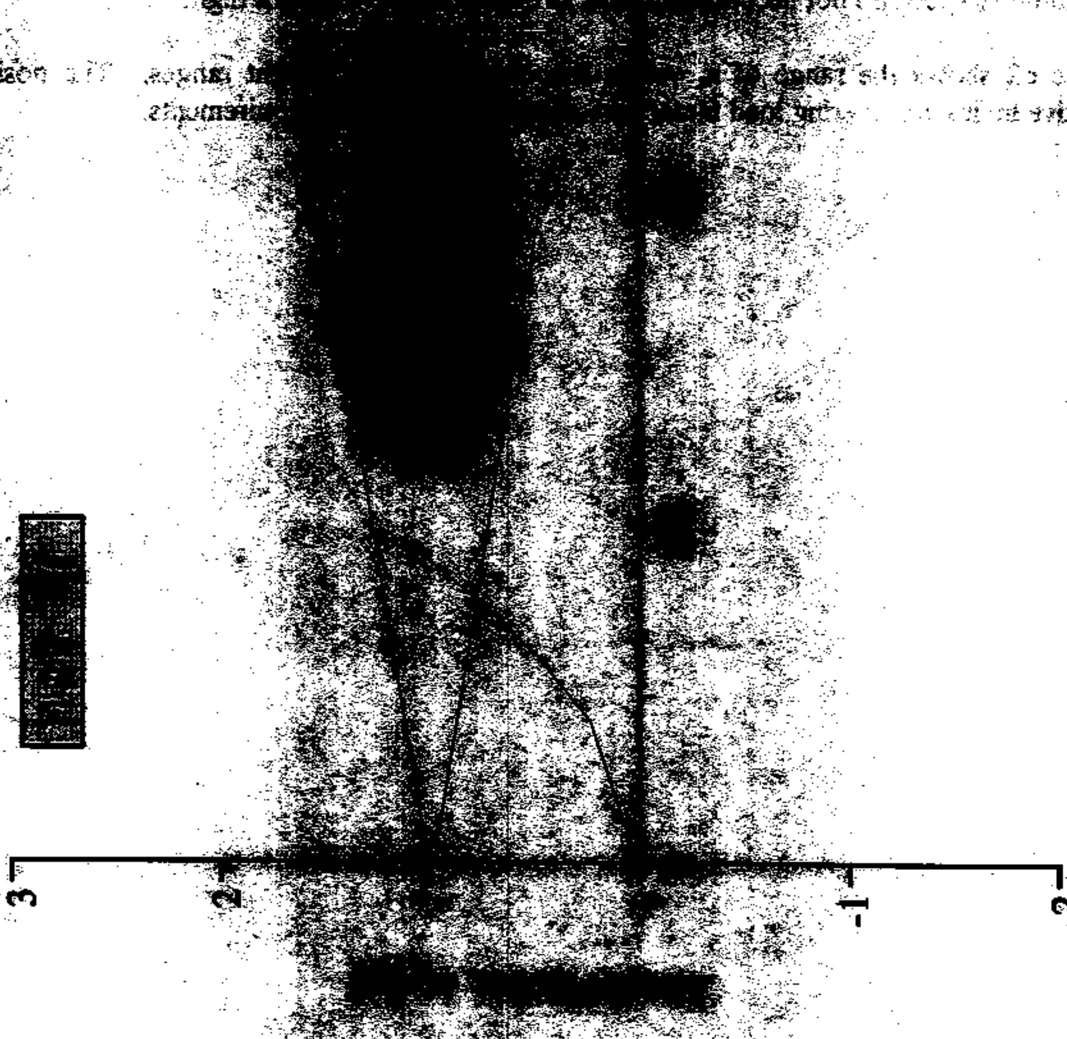
The limit load fa[illegible] outlined in table 9. The load factors for V[illegible] stall curve is also shown figures 57 and [illegible] shown at the limit velocity.

Sufficient data [illegible] conditions are not available this time [illegible] alternative diagrams, and the assumed [illegible] weight of 99,000 lbs, the reported [illegible] these diagrams.

8.0 ADDITIONAL DATA

Figure 60 shows the comparison [illegible] which an aircraft flight design limit [illegible] maximum altitude for many operators [illegible] noted that maximum Mach number [illegible] not [illegible] flight.

Figure 61 shows the range of [illegible] ranges. The positive negative [illegible] load [illegible] requirements.



[illegible] estimated by using [illegible]

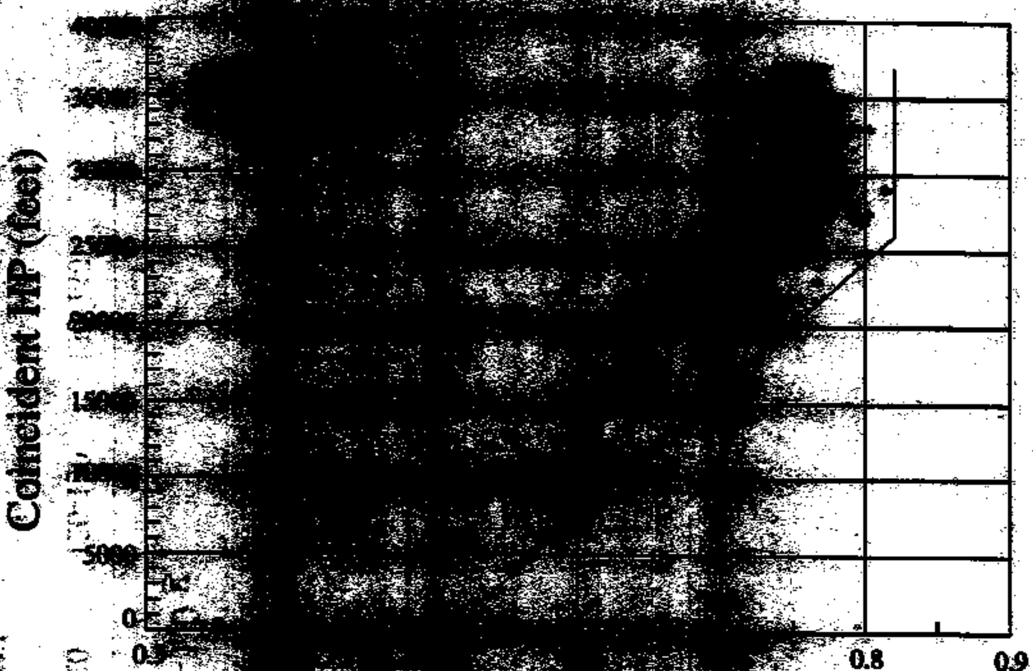
[illegible] table 9. These limit [illegible] is also shown. In [illegible] as the maximum [illegible]

[illegible] are not available at [illegible] diagrams, and all of [illegible] 000 lbs., the lowest [illegible] grams.

[illegible]TIONAL DATA

[illegible] shows the [illegible] number per flight. The [illegible] is shown in [illegible] altitude for maximum [illegible] speed, [illegible] maximum Mach and [illegible] airspeed do not [illegible]

[illegible] shows the range [illegible]. The positive and [illegible] limit maneuvering [illegible].



COINCIDENT [illegible] ER PER FLIGHT

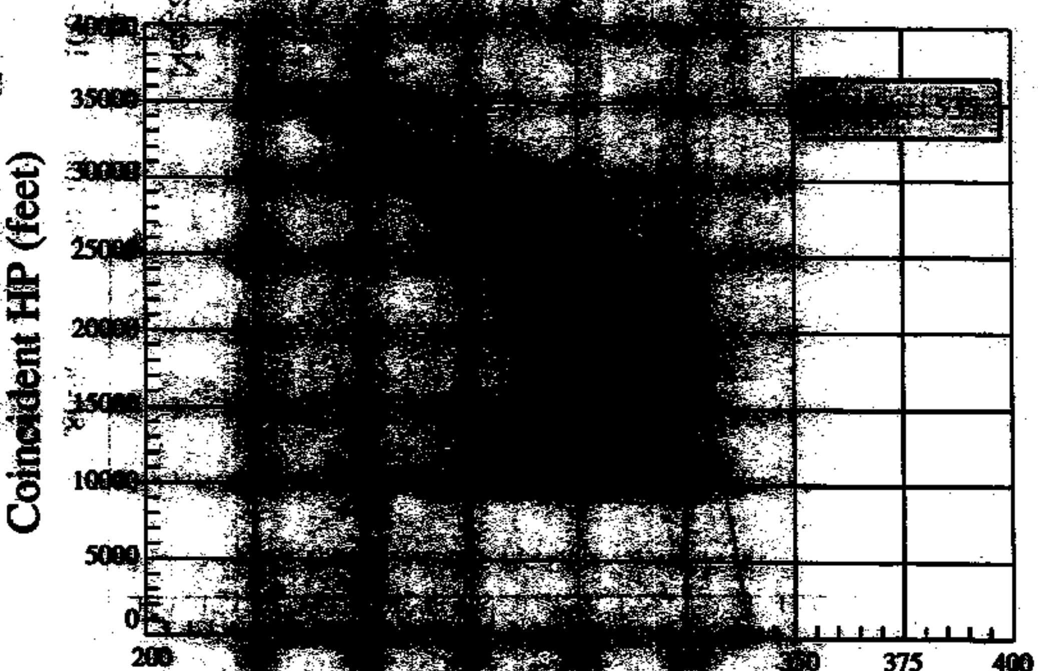


FIGURE [illegible] MAXIMUM

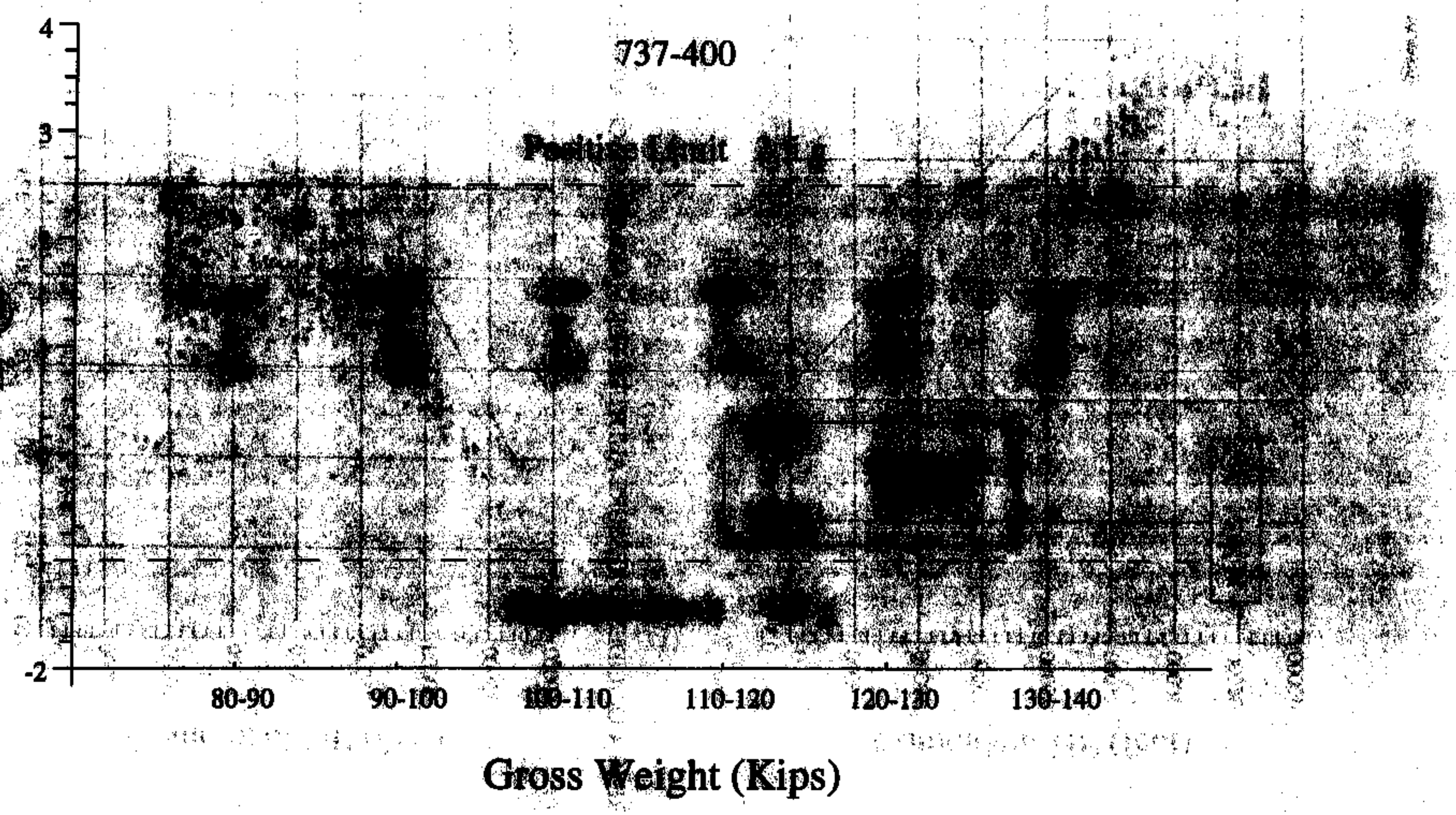


FIGURE 52. LIMIT MANEUVERING LOAD FACTOR PER GROSS WEIGHT BAND

[illegible] Program [illegible]
[illegible]-13000, [illegible]

Crabill, [illegible] System [illegible]
[illegible], September [illegible]

de [illegible] Data to [illegible]

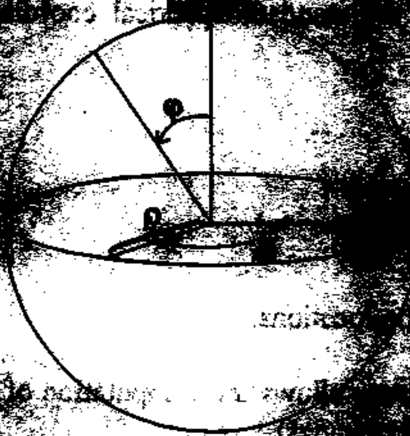
Crabill, N[illegible]ation of Methods [illegible]
[illegible] Results," D[illegible]

"Data from [illegible]7 Aircraft," T[illegible]
[illegible] No. FAA-[illegible]
[illegible] 1972.

Clay, [illegible] "Airline Operati[illegible]
Flight Manual [illegible]craft," Report No. FAA[illegible]
[illegible], September [illegible]

Press, H[illegible] of Estimating [illegible]
[illegible] Gust [illegible] Committee for Aeronautics [illegible]
Technical Note [illegible], Langley Field, Va.

[illegible]



Given:

Latitude [illegible]
of Departure [illegible]
Destination [illegible]

Procedure: [illegible]

The standard mathe[illegible] in which three variables specify location: ρ, φ, [illegible]

Let a **= Great Circle [illegible]**

Latitude is measured [illegible] (+90°) and the South Pole (-90°); whereas in the [illegible] North Pole, Equator, and South Pole lie at 0°, 90°, [illegible]

$$\varphi = 90° - \text{[illegible]}$$

transforms latitude [illegible] spherical coordinate system

Then

b = 90° - Lati[illegible]
c = 90° - Lati[illegible]
where b and c are values [illegible], respectively.

GREAT CIRCLE [illegible]

[illegible] spherical coordinate [illegible]

[illegible] computation of the [illegible]

[illegible] cos b cos c [illegible]

[illegible] b, c, and A [illegible]

[illegible] = cos (90° – L[illegible]

+ [illegible])

[illegible] – Lat [illegible]

[illegible] (90° - Lat[illegible]) = [illegible]

[illegible] (90° - Lat[illegible]) = [illegible]

[illegible] (90° - Lat[illegible]) = [illegible]

[illegible] one obtains [illegible]

[illegible] = sin (Lat[illegible] [illegible] – Lon_{Dep})

[illegible] the angular [illegible] and destination [illegible] obtained as

$$a = \cos^{-1} [\sin (Lat_{Dep}) \ldots [illegible] \ldots - Lon_{Dep})]$$

[illegible] a expressed in radians

$$GCD = a \text{ radians} \left(\frac{180 \ldots}{\ldots} \right) \left(\ldots \right)$$